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Ernest E. Thum, Editor

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RYERSON STEEL

By George K. Manning
Battelle Memorial Institute
Columbus, Ohio

End-Quench Hardenability Versus Hardness of Quenched Rounds

THE end-quench hardenability bar has acquired wide use in the past several years as a means of predicting the behavior of a particular steel during the quenching of some commercial part. One way of using the data is to correlate by experiment the hardness obtained at, say, the center of some commercial part with the hardness obtained at some particular position on the end-quench bar. It is supposed that the reference point established on the end-quench bar for one steel will also apply for other steels. If the Rockwell hardness at, say, the center of a commercial part made of a certain steel is found to be C-30 after a standard hardening treatment, then the distance from the quenched end of a hardenability bar of the same steel which is C-30 hard is determined as a reference point. Another steel developing a hardness of C-40 at the same reference point on the end-quenched bar would be expected to produce a hardness of C-40 at the center location of the commercial part in question. This line of reasoning is probably valid and will probably give results accurate to production limits so long as the steel composition is not radically changed.

Recently there has also been an increasing number of attempts to translate this correlation from hardness to a definite cooling rate. The reasoning is that for a given steel and given austenitizing treatment, the hardness (and microstructure) is dependent upon cooling rate and cooling rate alone. If this is true, then it follows that positions having similar cooling rates will exhibit similar hardnesses and microstructures. Hence, if the cooling rates at different positions along the end-quenched hardenability bar are known, and if the cooling rate at some particular location within a commercial part is known, then the metallurgist can predict hardnesses and microstructures from end-quenched hardenability tests.

This line of reasoning is open to question.

Metallurgists, as a group, have long neglected the fact that Gibbs's phase rule in its complete form contains one more degree of freedom than they are accustomed to using. This extra degree of freedom is *pressure*. Since, in studies of metallurgical equilibrium, changes in pressure involve only atmospheric pressure changes, and since the volume changes of metals are small during heating and cooling, the pressure dimension in *equilibrium* studies has justifiably been neglected.

However, it does not follow that pressure (or stress) can be neglected in studies involving kinetics. In the presence of severe thermal gradients, severe thermal pressures (or stresses) certainly occur. Allotropic volume changes which are very slow during long tests approaching equilibrium may occur very rapidly during fast cooling. Volume changes near the cooler surface of a part must certainly affect the stress pattern present near the warmer center of the same part. The so-called LeChatelier-Braun principle suggests that, because the transformation of austenite involves an increase in volume, tensile stresses (or negative pressures) should tend to promote the reaction, while compressive stresses (or pressures) should tend to inhibit it.

Though there are theoretical reasons for believing that this will be the *tendency*, it remains to be proven whether this tendency is of sufficient magnitude to be of practical importance. This paper is an attempt to shed some experimental light on this question.

Table I — Chemical Analysis of Steels

Steel	C	Mn	Si	S	P	Ni	Cr	Mo
A	0.44	0.71	0.21	0.020	0.020	0.08	0.25	0.12
B*	0.44	0.91	0.22	0.026	0.020	0.09	0.01	0.05
C	0.43	0.96	0.25	0.020	0.016	0.57	0.54	0.27
D	0.49	0.72	0.30	0.034	0.019	0.52	0.54	0.20

*Boron treated.

An analysis of the stresses in even a very simple part during quenching is impossible at the present time. One would have to know, first, the coefficient of expansion, modulus of elasticity, and stress-strain diagram of austenite and its transformation products over a wide temperature range; second, stress-relaxation patterns for austenite and also its transformation products as a function of time, again over a wide temperature range; third, the volume changes which occur as austenite transforms at various temperatures; fourth, the heat evolved during transformation of austenite at various temperatures; and fifth, an accurate knowledge of the cooling cycle. At the present time, only crude approximations of these various factors are available — but even if precise data could be obtained the mathematical treatment for a simple round bar would be exceedingly complex.

For this reason, a direct approach to the problem is impossible. However, the cooling cycle of a number of positions along the end-quenched hardenability bar and the cooling cycle of several positions within rounds of different sizes have been accurately determined by Weinman and Boegehold in an as-yet unpublished research for the O.S.R.D. on the heat treatment of N.E. steels for ordnance material. With this data it is, therefore, possible to compare the relationship between the hardenability bar and round specimens on the basis of equal cooling rates, with the relationship between the hardenability bar and round specimens on the basis of either equal hardness or of similar microstructure.

If the relationship, on the basis of equal cooling rate, coincides with the relationship on the basis of both hardness and microstructure, it must be concluded that cooling rate and composition are the only factors which *appreciably* affect the transformation of austenite. On the other hand, if these relationships do not coincide, it must be inferred that some factor other than cooling rate and composition is capable of affecting the decomposition rate of austenite. If the latter is found experimentally to be true, it would be logical to believe that stress is the unconsidered factor.

To explore this possibility that some factor other than cooling rate and chemical composition may affect the hardness and microstructure of quenched steel, the hardness of a number of quenched rounds was compared with end-quench hardenability data of the same steels. Results of these experiments will now be presented.

End-Quench Tests

Four openhearth steels, low in alloy yet covering a considerable range of hardenability and of better than average cleanliness and soundness, were selected. All four were aluminum-killed and had a McQuaid-Ehn grain size of 6 to 8. Chemical analyses are given in Table I. Specimens were forged ¼-in. oversize, normalized by holding for 1 hr. at 1700° F., and machined to the final sizes, selected to be appropriate with the hardenability of each steel.

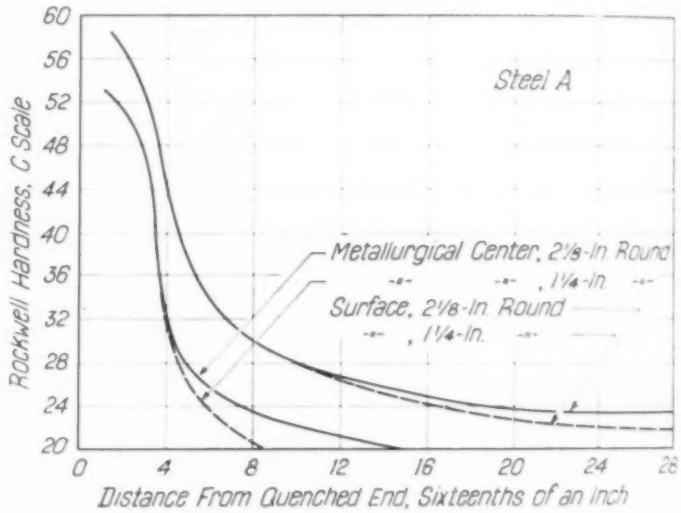


Fig. 1 — End-Quench Tests Machined From Large Rounds and From Smaller Rounds Forged Therefrom Show That Forging Has a Negligible Effect on Hardenability

Standard, shouldered, end-quench bars were cut from the largest and also the smallest diameter stock used in each steel in such a way that hardness surveys could be made on the end-quench bars at locations corresponding to the center and surface of the machined rounds. The end-quench bars were heated for 20 min. total time at 1650° F. and quenched in the standard manner. In this way an appreciable difference in hardenability was found between the metallurgical center (axis) and the surface of Steels A and C, due undoubt-

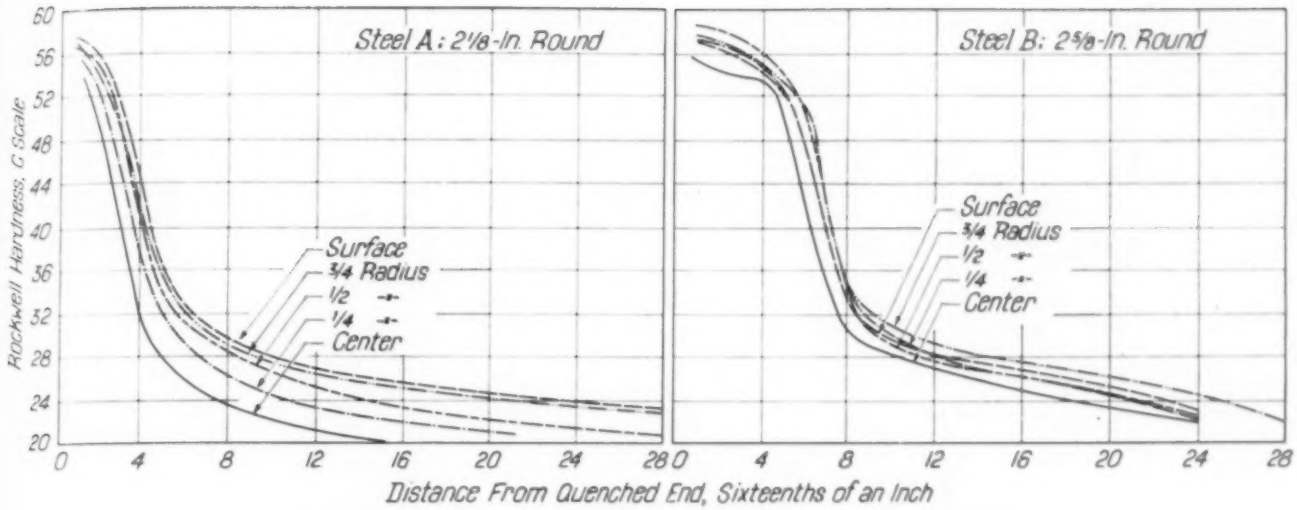


Fig. 2 and 3 — Variation in Hardenability of Steels A and B, Depending on Position, Ranging From Axis to Surface of Large Round

edly to the segregation of alloying elements in the original ingot.*

However, comparison of specimens cut from the largest and from the smallest diameter stock indicated that the forging operation itself had no appreciable effect on hardenability. Thus, Fig. 1 shows the hardenability data obtained at the surface and center of Steel A. Data for the other three steels listed in Table I were similar and have not been reproduced.

*Describing the test pieces in other words, a standard end-quench bar was machined from a large round in such a way that an element of its cylindrical surface (properly referenced) corresponded to the axis of the original round, and this referenced element was the location of the hardness survey after the test bar had been given the standard treatment. A similarly referenced element of the cylindrical test bar corresponded to the surface of the large round, and hardness was surveyed at this location.

Although the effect of forging on hardenability was considered to be negligible, it was found that the radial position within the bar was not negligible. Therefore, if various positions below the surface of quenched rounds were to be correlated with hardenability data, the latter must correspond to the locations intermediate between the surface and center of the original stock. Consequently, the hardenability bars cut from the largest round of each steel were ground and reference-marked in such a manner that a hardness survey could be made at locations corresponding to the center, ¼ radius, ½ radius, ¾ radius, and surface of the original stock.

Results thus obtained for all four steels are shown in Fig. 2 to 5. Smooth curves have been drawn to represent the data; however, deviation of individual points from the smoothed curve never exceeded one point on the Rockwell C scale.

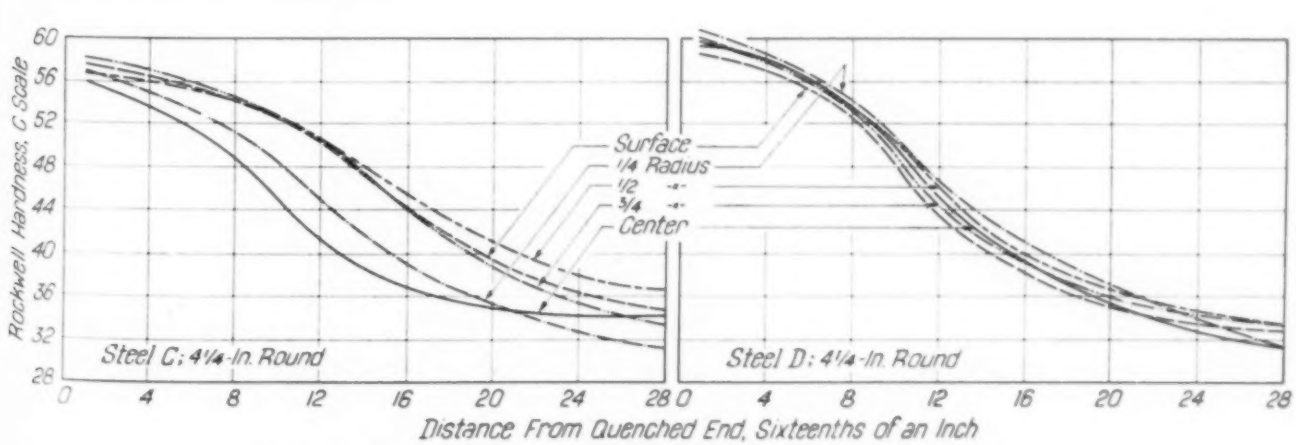


Fig. 4 and 5 — Variation in Hardenability of Steels C and D, Depending on Position, Ranging From Axis to Surface of Large Round

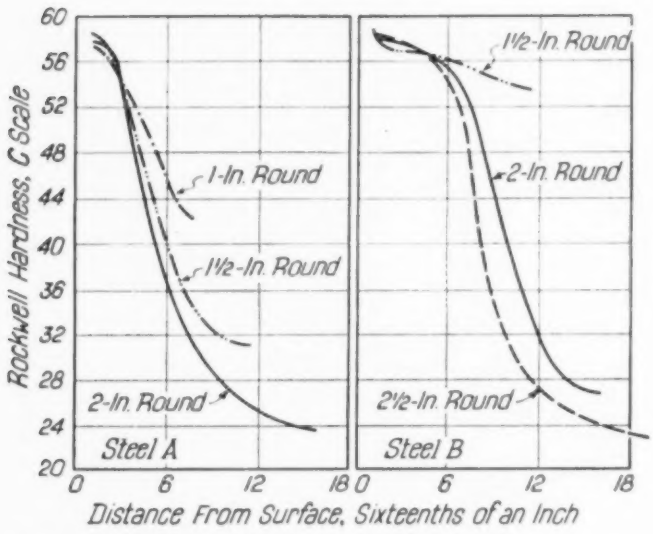


Fig. 6 — Hardness Traverses on Quenched Rounds of Steels A and B

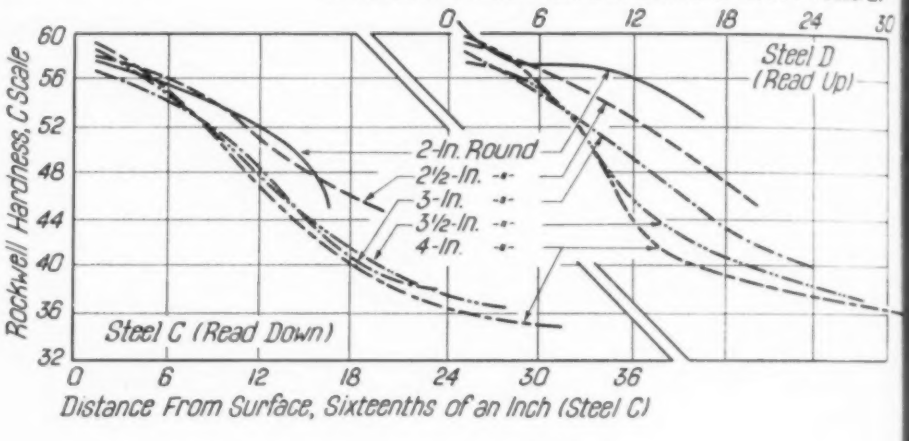
Steels B and D exhibited only a narrow spread in hardenability, Steels A and C a considerably larger spread, axis to surface.

Treatment of Rounds

Rounds of various diameters, 8 in. long, were machined from each steel. A cap made of $\frac{1}{16}$-in. steel sheet, containing a ¼-in. layer of asbestos paper, was brazed to both ends of each round to reduce heat extraction from the ends during quenching. The rounds were heated at 1650° F. for different times, depending upon their diameter; the total number of minutes in the austenitizing furnace was 20 times the diameter of the round in inches.

Following the austenitizing treatment, the rounds were quenched by immersing them vertically in an upward flowing column of water maintained between 70 and 80° F. Since the results were to be compared with cooling data previously obtained by Weinman and Boegehold, the quenchant velocity was made to coincide as nearly as possible with the velocity they used, and the water flow was adjusted to have an average velocity of 200 ft. per sec. in the annular space surrounding the specimens.

Fig. 7 (Below) — Hardness Traverses on Quenched Rounds of Steels C and D



Rounds were then sectioned with an abrasive wheel in such a way that ½-in. disks were

Table II — Comparison of Predicted and Actual Hardnesses of Four Steels at Center of Quenched Rounds, ½ Radius and ¾ Radius

	Diameter of Round																				
	1 In.*			1½ In.*			2 In.*			2½ In.*			3 In.*			3½ In.*			4 In.*		
Steel A: Predicted	*43*	*54*	**56**	*30*	*44*	**54**	*26*	*34*	**52**												
Actual	*43*	*52*	**56**	*31*	*41*	**54**	*24*	*31*	**47**												
Discrepancy	*0*	*−2*	**0**	*+1*	*−3*	**0**	*−2*	*−3*	**−5**												
Steel B: Predicted				*53*	*57*	**57**	*41*	*54*	**56**	*30*	*41*	**55**									
Actual				*53*	*56*	**57**	*26*	*51*	**57**	*23*	*32*	**56**									
Discrepancy				*0*	*−1*	**0**	*−15*	*−3*	**+1**	*−7*	*−9*	**+1**									
Steel C: Predicted							*51*	*56*	**57**	*48*	*55*	**57**	*43*	*54*	**57**	*39*	*52*	**56**	*36*	*49*	**55**
Actual							*45*	*55*	**56**	*44*	*53*	**56**	*38*	*49*	**54**	*36*	*45*	**54**	*35*	*42*	**53**
Discrepancy							*−6*	*−1*	**−1**	*−4*	*−2*	**−1**	*−5*	*−5*	**−3**	*−3*	*−7*	**−2**	*−1*	*−7*	**−2**
Steel D: Predicted							*56*	*57*	**59**	*53*	*55*	**58**	*48*	*52*	**57**	*42*	*49*	**56**	*38*	*44*	**55**
Actual							*53*	*57*	**58**	*45*	*54*	**58**	*40*	*49*	**55**	*37*	*44*	**54**	*36*	*40*	**53**
Discrepancy							*−3*	*0*	**−1**	*−8*	*−1*	**0**	*−8*	*−3*	**−2**	*−5*	*−5*	**−2**	*−2*	*−4*	**−2**

******Figures in italic type represent data for center of rounds;* figures in roman type represent data for ½ radius; **figures in bold face represent data for ¾ radius.**

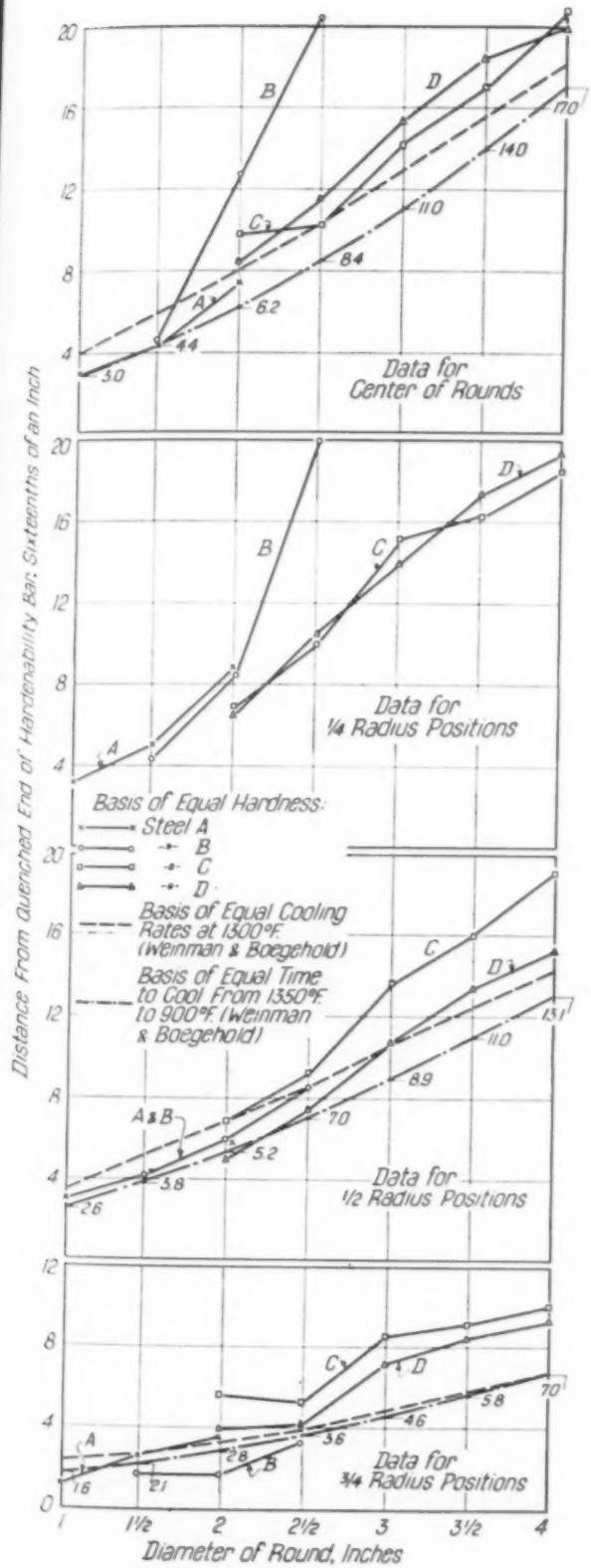

Distance From Quenched End of Hardenability Bar, Sixteenths of an Inch
Data for Center of Rounds
Data for 1/4 Radius Positions
Data for 1/2 Radius Positions
Data for 3/4 Radius Positions
Basis of Equal Hardness: Steel A, B, C, D
Basis of Equal Cooling Rates at 1300°F. (Weinman & Boegehold)
Basis of Equal Time to Cool From 1350°F. to 900°F. (Weinman & Boegehold)
Diameter of Round, Inches

*Fig. 8 — **End-Quenched Bar Locations Equivalent in Hardness to the Hardness at Various Positions in the Cross Section of Round Bars of the Respective Steels.** Figures on the lower curves are distances on end-quench bar in 1/16 in., predicted by Weinman and Boegehold's data, based on equal time to cool from 1350 to 900° F.*

wheel in such a way that ½-in. disks were obtained, one surface of which was midway along the length of the original specimen, and this surface was ground.

In order to be sure that this cross section had not been overheated and tempered during the cutting or grinding operation, the disks were etched, first in a solution of 5% nitric acid by volume in water at 140° F. for 10 sec., and then in a solution of 50% hydrochloric acid by volume in water at 140° F. for sufficient time to remove the smudge developed in the first solution. (This procedure has been found to be an extremely sensitive way of revealing heat-affected and tempered areas in hardened specimens.) Any of the disks showing even a slight amount of discoloration (tempering) were reground and re-etched until the surface was satisfactory in this respect.

Rockwell determinations were made on these hardened disks at $\frac{1}{16}$-in. intervals along two perpendicular diameters, and results of these four surface-to-center surveys were averaged for each round. The averaged values have been recorded in Fig. 6 and 7. A smooth curve has been drawn to represent the data; however, deviation of the smooth curve from any average value never exceeded one point on the Rockwell C scale.

Comparison of Data

The data of Fig. 2 to 7 have been replotted in Fig. 8 at left in such a way that each point represents the location along the appropriate end-quenched bar at which the hardness was equal to the hardness obtained at a given position within a round specimen of the same steel. If the hypothesis is correct that austenite transformation is solely a function of cooling rate and composition, then the points at the respective locations for the four different steels should fall one on top of another. As a matter of fact it is quite obvious that the points for the different steels do not coincide. The points for Steel B at center of rounds, particularly, stand out as differing in this respect, but the agreement between points for the other steels can hardly be termed acceptable.

Weinman and Boegehold's relationship based on cooling data is also represented in broken lines for center, ½ radius and ¾ radius positions. These investigators used two procedures in plotting their data, one based on equal cooling rates at 1300° F., the other based on equal time to cool from 1350 to 900° F., and found the latter more accurate for predicting hardness of small-sized rounds. (Theoretical considerations would also suggest the desirability of basing the correlation upon time to cool from 1350 to 900° F. rather than upon the cooling rate at 1300° F.) Although 1-in., 1½-in., and even 2-in. rounds give points based on hardness which agree well with locations based on time to cool from 1350 to 900° F., the larger-sized rounds did not.

Figure 8 suggests that if the hardness at some locations in a round is predicted from a knowledge of cooling rate and end-quench hardenability data, the prediction may not be accurate, but these plots do not indicate how large the errors may be. Table II shows the difference between the actual and the predicted hardnesses.

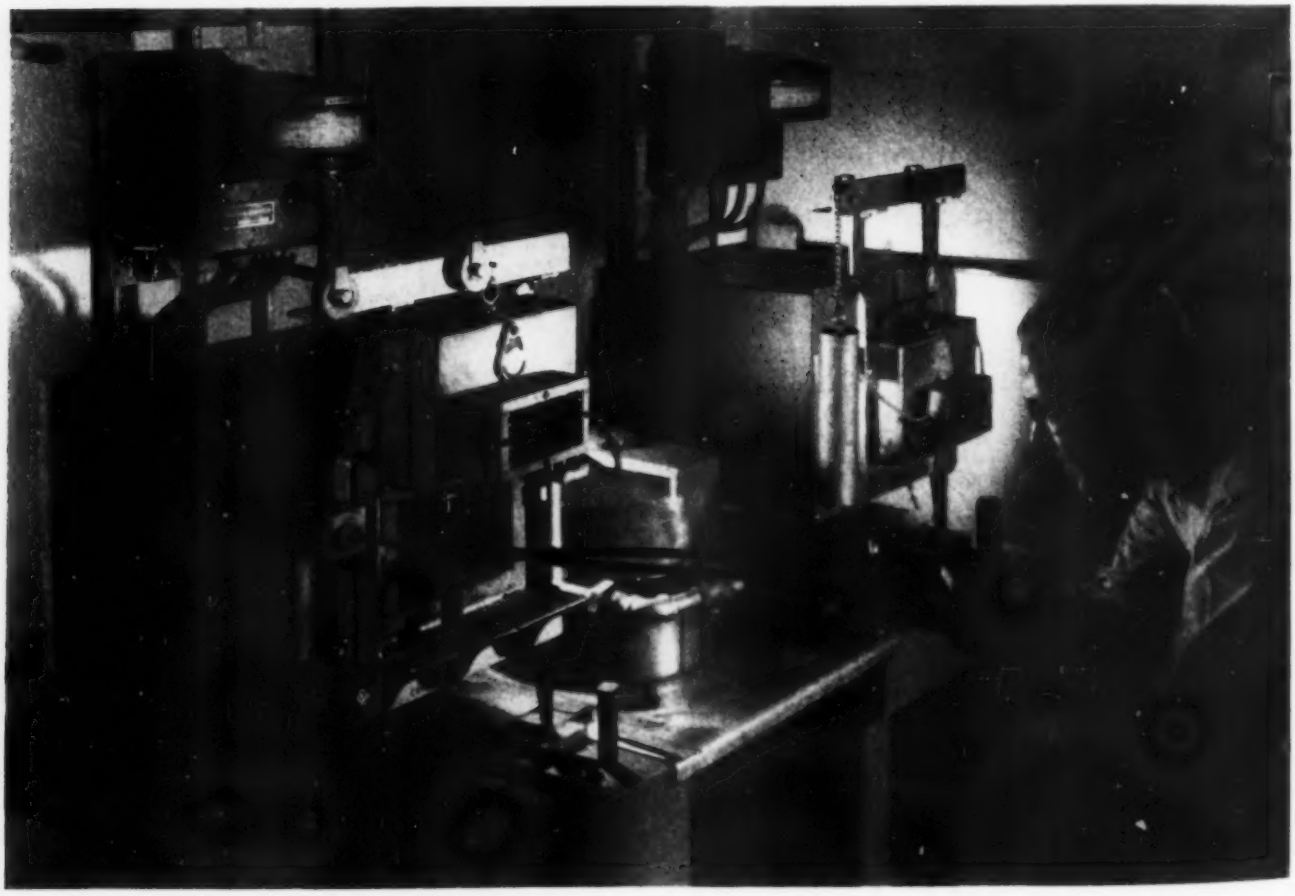
The largest discrepancy occurred in the center value of a 2-in. round of Steel B and amounted to 15 points on the Rockwell C scale. In this particular case it would have been predicted from the end-quench bar that the microstructure at the center of the 2-in. round would consist of about 90% bainite and martensite and 10% pearlite. Actually, the microstructure contained about 20% bainite and martensite and 80% pearlite.

Other hardness discrepancies ranged from 9 points to zero, with quite a number greater than 5 points. It is perhaps significant that the actual hardness was greater than predicted in only three instances and then the discrepancy was only +1. If allotropic and thermal stresses are the cause of these discrepancies, then it must be that tensile stresses are likely to be present at the proper time to advance the transformation — in other words, to cause transformation to occur at a higher temperature than predicted by the cooling rate. On the other hand, it must also be true that compressive stresses are not likely to be present at the proper time to impede transformation.

Summary

It was found that it was not possible to predict accurately the hardness of a round from a knowledge of end-quenched hardenability data and cooling rates. The discrepancy between actual and predicted hardness tended to increase with the diameter of the round. It may be possible to make an arbitrary correlation between the end-quench hardenability and the hardness of a certain part based on actual hardness tests, but even this correlation would be expected to become unreliable if the steel composition is decidedly changed. Stresses caused by allotropic transformation and thermal gradients during quenching are regarded as the probable reason for the failure to obtain a good correlation between predicted hardness based on equal cooling rates and actual hardness.

Two Small Furnaces With End-Quench Fixture Between, in Laboratory of Joseph T. Ryerson & Son



By T. J. Dolan*
and O. Sidebottom*
Urbana, Ill.

Raised (?) Yield Point in Bend Tests

reinterpreted, and may lead to unsafe design practices if used blindly. The importance of correct conclusions is further emphasized by the fact that several investigators have accepted the statement that the "yield stress is higher when a stress gradient exists", and have attempted to use it as an axiom in explaining the behavior of materials subjected to repeated loading or to other basically different service conditions. The excellent test data presented by Mr. Brewer are not disputed, but a review of the significance of the experimental curves and a comparison with the behavior that may be predicted theoretically for a beam whose fibers exhibit the same strength properties as those of tension specimens indicates that the yield strength (however measured) of the metal in a beam *is not* greater than in a simple tension member of the same metal.

THE ARTICLE "Raised Yield Strength in Bend Tests" by Given Brewer which appeared in the December 1945 issue of *Metal Progress* argued that greater stresses can be developed in a steel beam before the metal reaches its proportional limit or its yield strength than the proportional limit or yield strength obtained from a tensile test of the same material. In the May issue of *Metal Progress*, page 975, Mr. Brewer admits that his testing equipment is not accurate enough to prove unequivocally that the *tangent* yield is raised in the bend test, but has reasserted his conclusion that a greater yield strength can be safely used in design formulas for flexural members than the yield strength in tension.

Test results of several other investigators have been reported as showing that when the stress is nonuniformly distributed on a cross section of a member an "elastic" stress can be built up in the most stressed fiber which is greater than the stress at which yielding starts in a member made of the same material subjected to a uniformly distributed stress. (See for instance F. G. E. Peterson's paper entitled "Effect of Stress Distribution on Yield Points" in the *Proceedings* of the A.S.C.E., April 1946, page 445, and J. L. M. Morrison's "The Yield Point of Mild Steel With Particular Reference to Size of Specimen" in the *Journal and Proceedings* of the Institute of Mechanical Engineers, 1943, page 192.) The present writers feel that such conclusions may create false impressions if not

The changes in yield point that have been reported for a given metal under different test conditions involving uni-axial stress may be attributed to the following factors: *(a)* Difficulties of detecting the load at which yielding started in the most stressed fiber; *(b)* erroneous interpretation of the test data; *(c)* the varying stress levels at which the *upper* yield point phenomenon may be exhibited by certain mild steels under different test conditions. The following discussion will deal mainly with a study of items *(a)* and *(b)* as related to Mr. Brewer's test data; item *(c)* will not be discussed since the metals studied in his paper did not exhibit an upper yield point.

The most direct method of showing that the stress necessary to develop yielding in a beam is the same as the yield point in tension is to compare the experimental test data with the resisting moments that would be developed if each fiber of the beam were assumed to exhibit the same stress-strain relationship as that determined for a tension specimen. For example, if one uses an approximately correct stress-strain diagram in

*Respectively, research professor of theoretical and applied mechanics and special research associate in engineering materials at the University of Illinois.

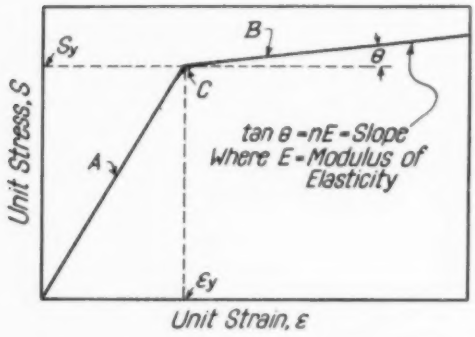


Fig. 1a — Hypothetical and Simplified Tensile (or Compressive) Stress-Strain Diagram Representing Conditions up to and Slightly Beyond the Yield Stress

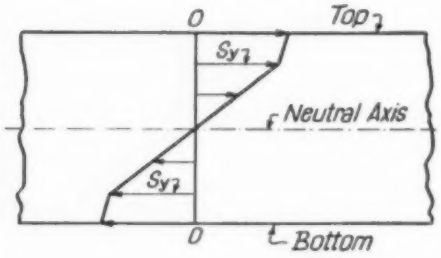


Fig. 1b — Assumed Stress Distribution in Beam After Initial Yielding at Extreme Fibers

tension or compression of the type shown in Fig. 1*a* and assumes that in a beam plane sections remain plane, it is possible to develop mathematical equations for various cross-sectional shapes based on equilibrium conditions relating the bending moment in the beam to the strains ε developed in the extreme fibers. If the assumed diagram (Fig. 1*b*) closely approximates the stress-strain relation in the beam, these equations would then apply for conditions of strain beyond the yield point where the ordinary flexure formula is not applicable.

The curves shown in Fig. 2 have been so derived using $n=0$ (material with a definite yield point S_y and a horizontal tangent to the stress-strain curve beyond the yield point) and have been plotted in terms of the dimensionless ratios M/M_y and $\varepsilon/\varepsilon_y$ to facilitate comparison for the four cross sections illustrated. As the relative volume of material in the extreme fibers is decreased by modifying the shape of the beam, there is a tendency for the curve to depart from the initial straight line less abruptly, leading to an illusion that the proportional limit has been raised. Actually, however, all curves begin to depart from the straight line when the moment $M/M_y=1$ is exceeded; the curves may all be representative of identical material, though the bending moment at which the deviation from tangency becomes a definitely measurable amount (as evidenced also by distortion of the member as a whole) is a function of the *shape* of the beam. For values of n (in Fig. 1) greater than zero, the initial deviations from the straight line relationship become even less pronounced and it is exceedingly difficult to determine experimentally the bending moment at which yielding began.

For actual metals there is often a slight rounding of the tensile stress-strain diagram as shown by the dotted line at *C*, Fig. 1. When using the theoretical equations this effect has been disregarded and the values of S_y and ε_y were obtained from experimental test data by extrapolating back from the portion *B* of uniform slope to obtain the intersection with the initial modulus line *A* in Fig. 1. By applying this concept to the tests reported by Mr. Brewer on a 2.502-in. diameter bar of S.A.E. 4140 (shown in his Fig. 1 and 3) the values of $S_y=115{,}000$ psi., $\varepsilon_y=0.00375$, and $n=0.080$ were obtained. Using these values in the theoretical equation shown in our Fig. 2 for a circular bar in bending, the moment-strain relation was computed and is plotted as the dotted Curve 3 in Fig.

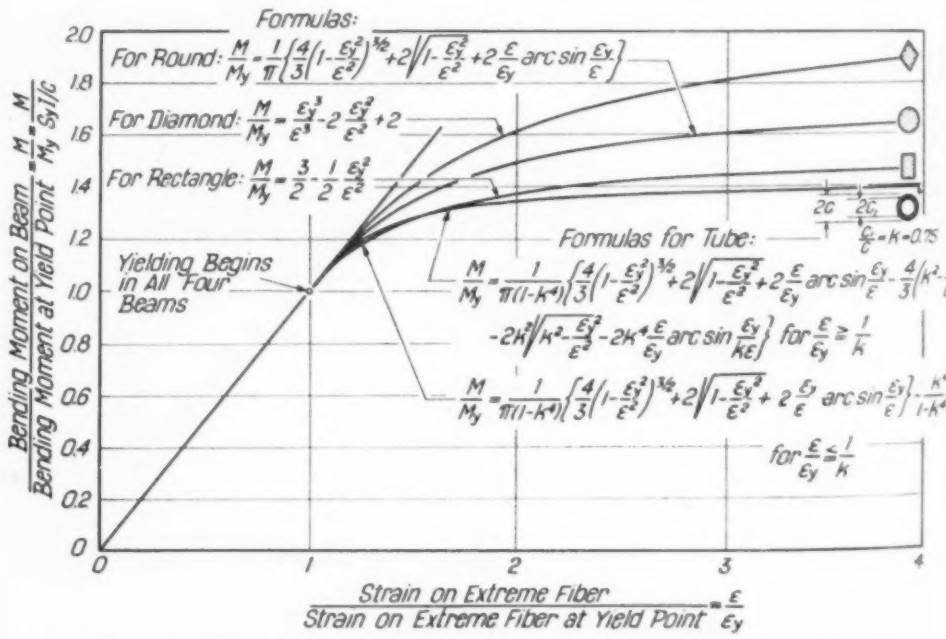

Formulas:
For Round: M/My = 1/π [4/3 (1 − εy²/ε²)^3/2 + 2 √(1 − εy²/ε²) + 2 (ε/εy) arc sin (εy/ε)]
For Diamond: M/My = εy³/ε³ − 2 εy²/ε² + 2
For Rectangle: M/My = 3/2 − 1/2 εy²/ε²
Formulas for Tube:
Yielding Begins in All Four Beams
Bending Moment on Beam / Bending Moment at Yield Point = M/My = S·I/c
Strain on Extreme Fiber / Strain on Extreme Fiber at Yield Point = ε/εy
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
1
2
3
4

Fig. 2 — Theoretical Moment-Strain Diagrams for Bend Tests on Bars of Four Cross-Sectional Shapes Made of a Given Metal With a Definite Yield Point S_y. (It is assumed that n of Fig. 1 is zero)

3. Mr. Brewer's tensile test data are shown as Curve 1, and the experimentally determined strains on the extreme fiber of the beam with the corresponding bending moments M (divided by the section modulus) are plotted as Curve 2.

It should be re-emphasized that above the value of stress S_y, the ordinates to Curves 2 and 3 in Fig. 3, though measured in psi., do not represent actual outside fiber *stresses* above the point of tangency, but show only relative values of total *load* M on the beam. The theoretical Curve 3 follows the general trend of the experimental Curve 2, but falls slightly below it, indicating that a slightly weaker material was assumed in the theoretical curve. This is explainable by reference to Mr. Brewer's Fig. 1 showing that the tensile test coupons were cut from an interior portion of the bar and had a slightly lower hardness (strength) than the extreme fibers of the beam. The derived Curve 3 based on the tensile test data would, therefore, be expected to show slightly lower strength properties than a test of the actual beam. The essential feature to be observed, however, is that

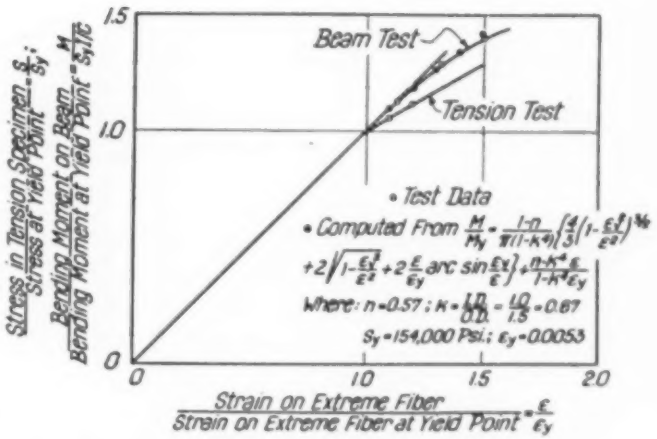

Beam Test
Tension Test
• Test Data
• Computed From
Where: n=0.57 ; K=
S_y=154,000 Psi.; ϵ_y=0.0053
Stress in Tension Specimen = S_x / Stress at Yield Point = S_y ;
Bending Moment on Beam = M / Bending Moment at Yield Point = $S_y I/c$
Strain on Extreme Fiber = ϵ / Strain on Extreme Fiber at Yield Point = ϵ_y
0
1.0
1.5
2.0

Fig. 4 — Comparison of Theoretical and Experimental Load-Strain Diagrams for Tension and Bending Tests for a Hollow Tube

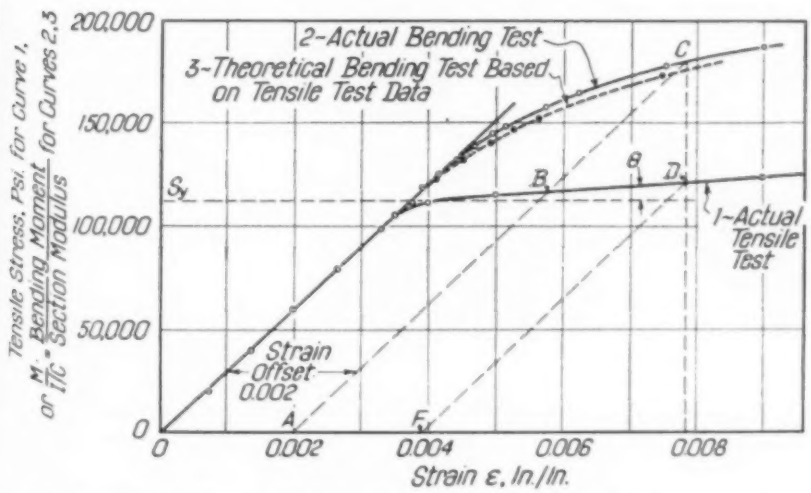


Fig. 3 — Comparison of Theoretical and Experimental Load-Strain Diagrams for Tension and Bending Tests for a Solid Cylindrical Beam

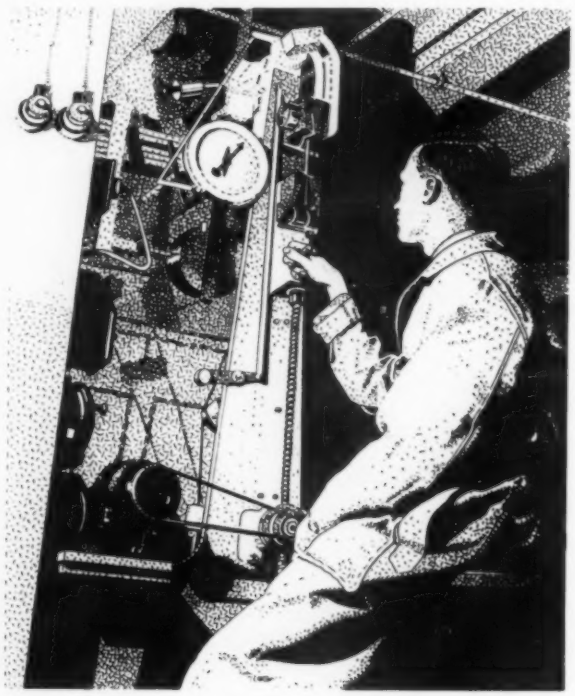
Curve 3 might appear under casual observation to exhibit a higher proportional limit and yield point than the corresponding values obtained from the tensile test, whereas the theoretical Curve 3 was actually computed for metal of practically identical strength properties to those of the tension specimen.

The present writers have made a similar comparison (Fig. 4) of the data on a round tube in bending originally presented in Mr. Brewer's Fig. 4. A close agreement exists between the experimentally determined strains in bending (shown by open circles) and those shown by solid circles computed from the tensile stress-strain curve. Thus the theory which assumes that yielding in a beam begins at the *same* stress in the material as the yield point determined from a tension test is sufficient to check with a fair degree of accuracy the experimental moment-strain diagram for a beam.

Moment-strain curves of the types in Fig. 2 and 3 are often misinterpreted until examined critically since they appear to exhibit the same characteristics as a stress-strain curve for a simple tension test. The important difference between Curves 1 and 3 in Fig. 3 is brought out by noting that while the strains (abscissas) in both curves are identical, the ordinates to Curve 3 are not equal to the stress in the extreme fiber for values greater than S_y. Therefore, the ordinates in the two diagrams corresponding to the same offset (for example, the line AC) have very different meaning with respect to stress, and hence the two curves cannot be analyzed in the same manner. The truth is that the stress and strain for the extreme fiber of the beam, represented by Point C in Fig. 3, correspond with the Point D on the tensile stress-strain curve; hence at Point C (or D) the total strain is more than twice that required to cause yielding at the stress S_y, and is accompanied by a large plastic set shown approximately by the abscissa OF. Thus the offset method of determining the yield strength in a tension test cannot be applied directly to determine yield strength *of the*

material from theoretical moment-strain curves.

Fundamentally, the resisting moment developed by a beam and plotted in a moment-strain curve represents an integrated sum of the resisting moments developed by all fibers of the member. After a minute plastic deformation has taken place on the extreme fibers, the resisting moment in an experimental test can be further increased, not because the elastic stress in the outer fibers is increased above the yield point, but primarily because of the yielding and redistribution of stress which occurs, whereupon a large volume of inner understressed fibers resist a greater proportion of the bending moment. Because of this potential load-carrying capacity of the fibers beneath the surface, the proportional limit (and yield strength) of the material in the surface of a beam is therefore more difficult to measure experimentally than in a simple tension member.



For many applications of beams made of ductile steel, considerable yielding of the outer fibers can occur without causing excessive curvature or deflection of the member, and hence for some uses we may infer that the beam is not structurally damaged as a whole. Thus, certain beams may resist satisfactorily loads greater than those required to start yielding in the extreme fibers, but it should be recognized that the increased useful strength of such a member is not due to "higher elastic stresses" of the metal by virtue of its shape, but is rather due to redistribution of stress whereby the understressed portion is permitted to offer greater resistance to the load without permitting sufficient plastic distortion to the member as a whole to constitute appreciable structural damage.

The curves reproduced in Fig. 2 indicate the relative extent to which beams of various shapes may be overloaded (stressed beyond the yield point) before appreciable damage is apparent by their relative deviations from a linear load-strain relationship. The plastic deformations of the metal in the extreme fibers corresponding to these small deviations from linearity are, however, rather large — as indicated roughly by the percentage by which the ratio ϵ/ϵ_y exceeds unity. This fact might require serious consideration in certain applications where danger of instability due to localized buckling may be aggravated by the plastic deformation of the most stressed fibers.

The writers differ with Mr. Brewer in the viewpoint that "a refined design is now based on the proportional limit of the material used". R. L. Templin has indicated many of the difficulties inherent in reproducing in successive tests a definite proportional limit, even in the tension test, in a paper in the 1929 *Proceedings* of the American Society for Testing Materials entitled "The Determination and Significance of the Proportional Limit in the Testing of Metals". It is an elusive property whose value is greatly influenced by all of the following factors: Speed of straining, type of testing machine, sensitivity of extensometer, scale to which results are plotted, the personal element in choosing the point of departure from a straight line, and the presence of small amounts of residual stress, cold work or eccentricity of loading. Furthermore, there is no fundamental relation between "elastic strength" and proportional limit; some elastic nonmetallic materials have a proportional limit at zero stress; conversely, even metals undergo small amounts of localized plastic deformation at stresses appreciably below their proportional limits as ordinarily determined with sensitive extensometers. Due to these inherent difficulties of reproducing a definite value, and since the most accurate value obtained is not necessarily indicative of the limit to avoid structural damage, it would appear inadvisable to revert to the use of the proportional limit as a limiting stress on which to base working stresses for structural design. The A.S.T.M. Standard E6 referred to by Mr. Brewer states: "It is usually impractical and probably impossible to determine the stress at which inelastic action in a member begins." On this basis the proportional limit has generally been discarded and the yield strength in tension adopted as a practical method of deter-

mining a measurable value of stress above which the amount of plastic yielding of the material is considered to be damaging and below which the damaging effects are considered to be negligible.

In conclusion, the basic behavior of flexural members as visualized by the writers may be summarized as follows:

1. The stress necessary to cause initial yielding of the most stressed fibers of a member subjected to a nonuniform stress distribution, such as occurs in a beam, is the same as that required to cause yielding under a uniform stress.

2. The nonuniform distribution of stress which occurs in a beam enables the member to resist static *loads* considerably greater than that required to start yielding of the extreme fibers. As indicated in Fig. 2, the shape of cross section of the beam will determine the extent to which plastic deformation of the extreme fibers may occur before structural damage is made evident by appreciable distortion of the whole member.

3. The proportional limit of a material is not a good criterion of the beginning of structural damage and, due to experimental difficulties of reproducing a definite value, it does not appear to be a suitable property on which to base design stresses.

Editor's Closure: In fairness to Mr. Brewer it should be said that his brief note in the correspondence pages of the May 1946 issue was cut down from a rather extensive letter containing data and curves quite similar to those in Fig. 3. His attitude was then, and still is, that he was in error in holding that experimental data secured by him and others constitute proofs that the proportional limit of the metal in the extreme fiber of a beam is higher than it is in a simple tension member. However, he wishes to re-emphasize a point — evidently not contested by his critics — that such data give a logical support to the practice of using a raised "modulus of rupture" for designing tubular beams in aircraft landing gear and guided missel spars which should operate at high stresses without suffering measurable permanent set. Savings in such items, where there is no probability of fatigue failure because of few repetitions of limit load, can amount to several hundred pounds of weight in a large airplane.

Maximum Carbon in Gas Carburizing

By Gerard H. Boss

Naval Air Experimental Station, Philadelphia Naval Base

HEAT TREATERS have found that very thin sections, such as shim stock, will carburize to much higher carbon concentrations than even the richest surface layers of ordinary carburized parts. Mr. Harris has reported in *Metal Progress* that the first 0.005-in. cut from the surface of carburized pieces contains the same amount of carbon as called for by the A_{cm} line of the iron-carbon equilibrium diagram. However, the much higher concentrations of carbon obtained on shim stock indicate that the carbon contents obtained along the surface of pieces of commercial thickness are perhaps the result of dynamic action short of equilibrium — that is, a balance, which may be constantly shifting, between the rate of carbon absorption at the surface and the speed of carbon diffusion to the interior.

Considered from this viewpoint, the interior metal of a large carburized part becomes a carbon sink of almost infinite capacity. It follows, then, that determination of the maximum carbon content attainable in carburizing can only be done when the mass of the metal is negligible in relation to the surface area exposed to the carburizing medium. In compacted powdered iron this condition is ideally met.

During the spring of 1940, while attending the graduate school of the University of Michigan and working under Dr. Schneidewind's direction, the writer investigated, in a preliminary way, the sintering of powdered iron compacts in a carburizing medium. Most of his results were qualitative; however, some of them may throw a little light on the problem of the absorption of carbon during carburizing.

For a sintering atmosphere, city gas (which

in Ann Arbor is piped natural gas) was used. Natural gas, being mostly methane, is an excellent carburizing medium. The sintering temperatures used were 2050° F., just below the melting temperature of the iron, iron carbide eutectic (ledeburite), and 2200° F. While no chemical analyses of the heat treated compacts were made, the carbon content can be estimated from the microstructure.

The left-hand photomicrograph below shows a compact which was sintered at 2050° F. for an hour, then air cooled. The structure consists of pearlite grains with massive cementite boundaries. The other view shows a piece which was sintered one hour at 2050° F., air cooled, and then reheated to 2050° F. for 20 min. and quenched in brine. This structure, which consists of martensite and massive carbide, had a hardness of Rockwell C-61 to 63 as compared to C-24 for the first specimen. It has a close resemblance to white cast iron.

In both these specimens the carbon content is well beyond the maximum solubility of carbon in austenite as indicated by the A_{cm} line at this temperature. In fact, the carbon is probably around 3.3%.*

In consideration of this, it seems as though carbon absorption is dependent on some sort of chemical affinity rather than upon a simple physical force urging towards solution. If this is true, the limiting line of solution (that is, the A_{cm} line) can be of no significance in determining the *maximum* percentage of carbon attainable. Rather, it is a function of the activity constants of the reactants. This may be an unorthodox conception but it seems to be capable of explaining the observed phenomena.

The pieces sintered at 2200° F. had a much lower carbon content, being of hypo-eutectoid composition. The writer believes that this was due to the closing together of the particles of the compacts, which occurred at this higher temperature, thus rapidly closing ingress of the carbonaceous gas. It is a fact that the voids usually found in sintered compacts were absent in all the specimens sintered at 2200° F.

*Planimeter measurement of a random strip across an enlarged copy of the micro of the annealed structure shows about 43% Fe_3C and 57% pearlite.

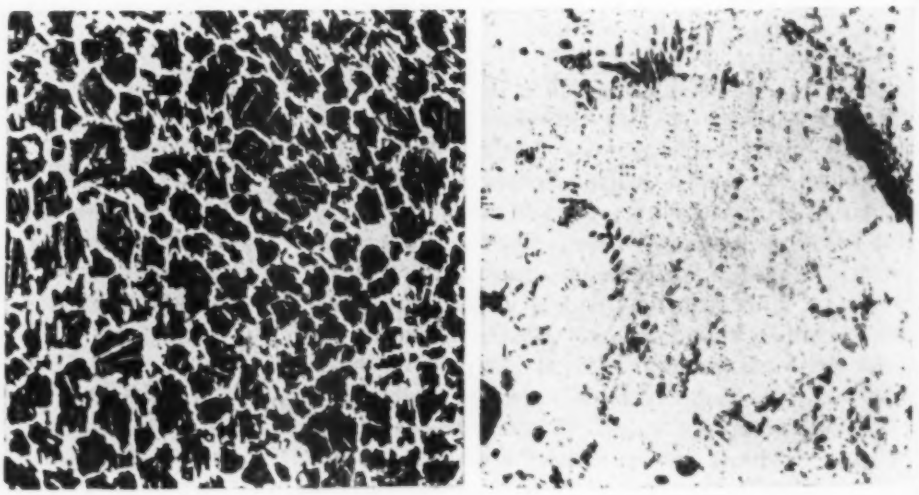
Bits & Pieces

Mounting Fine Wire for Cross-Sectional Examination

TO INSURE a properly aligned specimen of fine wire for cross-sectional examination, a simple but effective method for mounting is required for a Buehler, Fischer or similar type of specimen mounting press.

Place a half-inch length of wire on the base plug of the mold as a direction guide. Add a small amount of molding powder and place, parallel to the guide wire, one or more of the specimens to be examined. Add necessary molding powder and mold specimen mount in the usual manner.

Cut the mount through its longitudinal center at right angles to the guide wire (which will be exposed) with a hack saw or band saw. Either of the two halves of the original mount may then be prepared for metallographic examination of the



Iron Powder Compact Heated 1 Hr. in Natural Gas at 2050° F. Slowly cooled microstructure at left shows about 57% by area of pearlite grains and 43% by area of massive carbide envelopes—carbon about 3.3%. Sample reheated and quenched resembles white cast iron

exposed cross-sections. (R. L. DUFFNER, metallurgist, General Cable Corp.)

E. S. NORRIS, metallurgist for Sylvania Electric Products, suggests a variant on the above, wherein the guide wire is mounted at the bottom of a half-thickness slug, molding with the usual pressure but no heat for 30 sec., then arranging wires on top this slug, covering them with 100-mesh bakelite powder, then filling mold full height and finishing the mount with the conventional procedure. The portions molded separately will not break apart when the mount is sawed in two.

Edge Rounding Avoided With Cast Iron Grit

DURING the polishing of mounted specimens, metallographers have used various methods to prevent the plastic resin from wearing away faster than the imbedded alloy. Some laboratories mount scrap pieces of the same alloy around the specimen and others may surround the specimen with a ring of wire. These methods serve the purpose but are more time consuming than the simple technique we are using. We sprinkle particles of cast iron grit, such as is used in a grit blast cleaner, around the specimen after it has been placed in the mold. The bakelite or desired resin is then poured in and the regular mounting procedure is followed.

The following suggestions, derived from considerable experience, are offered:

1. A light sprinkling of cast iron grit usually serves to separate the particles. If they gather in clusters it is wise to separate them, because the plastic may not work through the pile and a cluster may fall out during polishing.

2. If electrolytic etching is used, do not allow the cast iron grit to touch the specimen, else undesirable etching effects may result.

3. The metallic specimen should be smooth and flat before mounting. If an excessive amount of metal and resin is polished away the cast iron grit may fall out.

4. If rough polishing must be resorted to after mounting, cool the specimen often because the small particles of cast iron grit heat up rapidly. Overheating will manifest itself by discoloring the enveloping resin. (ANTON L. SCHAEFFLER, metallurgist, Arcos Corp.)

Distinguishing the Common Aluminum Alloys

TO SUPPLEMENT the identification procedures for common aluminum alloys as presented by Vernon H. Patterson in Bits and Pieces in the February issue of *Metal Progress*, the following chemical tests may be employed without recourse to anodizing:

Copper is easily distinguishable in 11S, 17S, and 24S alloys as stated by him. If the excess sodium hydroxide is removed by gentle washing, and a drop of concentrated nitric acid added to the spot followed by a few milligrams of sodium bismuthate, the characteristic purple of permanganate is easily seen in 17S and 24S alloys. 11S aluminum alloy, which contains no manganese, gives no reaction. The same procedure will identify 3S aluminum; no blackening will occur due to the absence of copper, but nitric acid and sodium bismuthate will give a strong purple color if manganese is present.

For the identification of chromium, an adaptation of the method used for steel as printed previously in Bits and Pieces is applicable:

The following solutions are required:

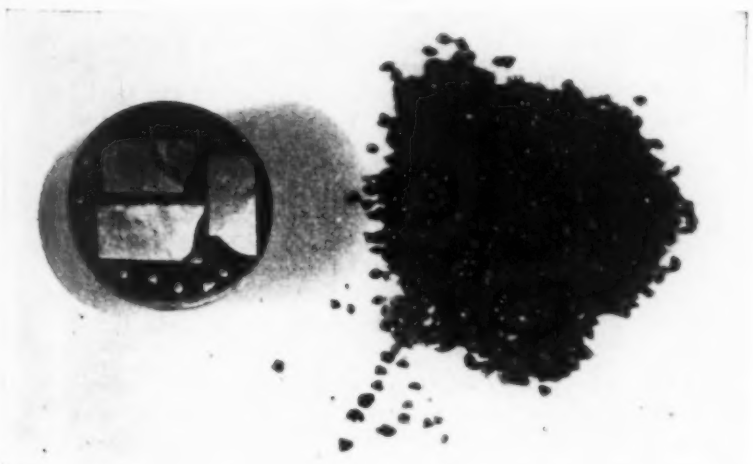
1.	Sodium hydroxide	20 grams
	Bromine	2.5 ml.
	Water	400 ml.

(Solution No. 1 decomposes and should be replaced every two weeks.)

2.	Conc. sulphuric acid	50 ml.
	Water	250 ml.
3.	Phenol	5 grams
	Glacial acetic acid	15 ml.
4.	s-diphenyl carbazide	0.10 gram
	Glacial acetic acid	5 ml.
	Ethyl alcohol	50 ml.

(Store solution No. 4 in a brown bottle, and replace when darkly colored.)

One drop of concentrated hydrochloric acid is allowed to react to completion on the unknown alloy.



Technical Aspects of Atomic Control

LAST December the ministers of foreign affairs of England, Russia and America agreed to ask the General Assembly of the United Nations to establish a commission to formulate a report on the control of atomic energy and its application for peacetime purposes and scientific research.[1] Such a commission was established on January 24, and its first meeting was held on June 15, when BERNARD BARUCH, American member, presented the outlines of a plan which followed fairly closely the so-called ACHESON-LILIENTHAL report published by our State Department on March 16.[2] In his presentation he emphasized that the various provisions were not to be subject to veto by individual nations.

At the second meeting of this commission (June 19), ANDREI GROMYKO, Russian member, proposed an alternative plan calling for the appointment of a committee for the interchange of scientific information, and another to draft agreements to outlaw atomic weapons.[3] His remarks indicated that Russia intended to insist on its veto powers, and on July 25 he said, "The United States' proposals in their present form cannot be accepted in any way by the Soviet Union either as a whole or in separate parts."

Meanwhile a committee of 12 physicists, one from each of the countries represented on the commission, had been appointed to study the scientific and technical aspects of the problem of control, and agreed upon a report, but it was not submitted until the Soviet representative could get his government's views. Approval was eventually given by S. P. ALEXANDROV, Soviet delegate, on September 26, in the following terms: "The committee had at its disposal, as is recognized in the report, limited and incomplete information. The majority of the conclusions in the committee's report are, therefore, hypothetical and conditional. With this reservation, I vote for adoption of the report."

One can only guess whether this implies a change in the Russian attitude expressed earlier by Mr. GROMYKO. The text of this report quotes frequently from the so-called SMYTHE report[4] in its references to the production and utilization of nuclear "fuels", and parallels the ACHESON-LILIENTHAL report when commenting on peaceful uses or dangerous and clandestine activities. The committee "limited ourselves strictly to the scientific and technical aspects of the question" even while recognizing that "problems of a non-technical or political nature would have to be taken into account in a system of control."

Two flow charts are included in the report showing the principal steps between the mining of uranium and thorium ores and the production of the three "concentrated nuclear fuels", U^{233}, U^{235} and Pu^{239}, and it is emphasized that accurate accounting for normal chemical and metallurgical losses is so difficult that clandestine diversion will be difficult to detect, the more so as the fuels reach the final stages of processing.

"THE mining operations take place along conventional lines and involve the handling of large quantities of ore, concentrates and tailings. It would hence appear feasible to keep track of the distribution of any significant quantities of material from the mines. A special significance must be attached to the devising of adequate safeguards against the diversion of raw materials, since none of the subsequent operations can proceed without uranium, or uranium and thorium.

"Extraction and production processes normally involve losses comparable with those in other industrial chemical activities. These provide an opportunity to conceal diversion by making it appear that only process losses have occurred.

"Preparation of the metal from the uranium or thorium compounds also involves process losses which may be used to conceal diversion. . . .

"Clandestine manufacture of atomic weapons from nuclear fuels diverted from stocks or from the plants producing such fuels would be extremely difficult to discover because the operations involved can be carried out in comparatively small installations which could easily be concealed. . . .

"We must not overlook that with certain systems of control one would have to consider the possibility that plants or materials might be seized. . . . a danger the greatest in the case of seizure of stocks of concentrated nuclear fuel, because from that stage weapons would be produced most quickly and in relatively small plants. A wide geographical dispersal of stocks and plants and the restriction of stocks to minimum operating levels would reduce the risk."

Finally the committee notes that:

"The maintenance and strengthening of the international community of scientists, the free exchange of scientific information and an increasing awareness among all scientists of one another's research activities would assist in making less likely the application of research talent to clandestine activities. . . .

"With regard to the question posed 'whether effective control of atomic energy is possible,' we do not find any basis in the available scientific facts for supposing that effective control is not technologically feasible. Whether or not it is politically feasible is not discussed or implied in this report, nor is there any recommendation of the particular system or systems by which effective control can be achieved."

ABOUT the only new information contained in this report is a sketchy account of how thorium metal enters the picture. Appendix II is a flow sheet showing the concentration and refining of thorium from ore deposits or by-products, with

[1] See *Metal Progress*, January 1946, page 127. [2] Summarized in *Metal Progress*, May 1946, page 992-3. [3] See *Metal Progress*, July 1946, page 83. [4] Full abstract in *Metal Progress*, December 1945, pages 1313-44. [5] Presumably U^{235} or Pu^{239}; conceivably some other radioactive metals or isotopes.

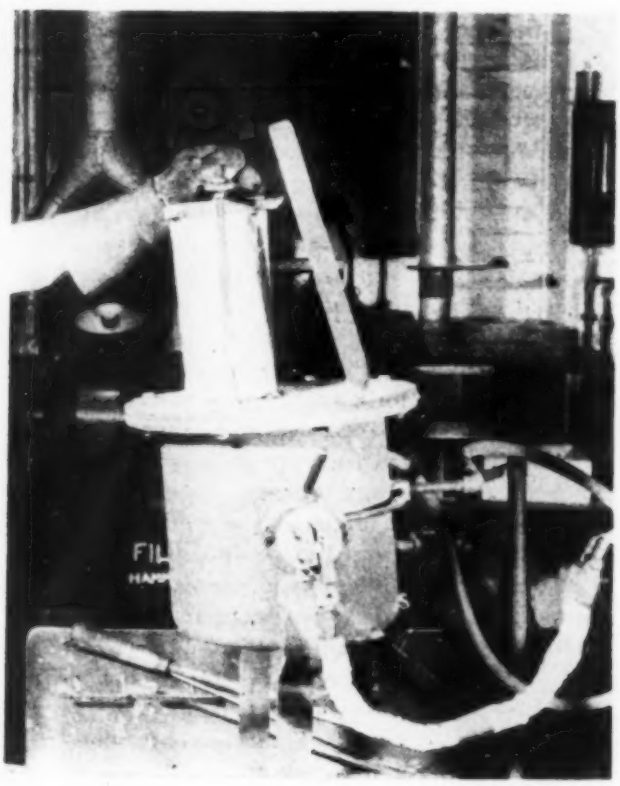
the eventual production of purified metal. In a suitable reaction this metal plus "nuclear fuel"[5] produces U^{233}, which can be separated from its associates into a "concentrated nuclear fuel". "Available information indicates that the utilization of thorium is less thoroughly explored than that of uranium, but is theoretically possible."

This is transferred by a glass rod to the depression of a spot plate which contains two drops of solution No. 1. The mixture is stirred for 10 to 20 sec. and then one drop of solution No. 2 added, stirred, and followed by one drop each in order of solutions No. 3 and 4.

The characteristic rose color of the diphenyl carbazide-chromium complex, although faint, is easily discernible in 52S, 53S, and 61S alloys. (FRANK C. BENNETT, Jr., Camera Works, Eastman Kodak Co.)

Skulls Prevented by Boron Nitride

VERY OFTEN in foundry work some difficulty is had with molten metal sticking to furnace mouths and forming skulls in small ladles. This trouble may be eliminated by painting a mixture of boron nitride and water on the warmed surface. The water quickly evaporates and leaves a film of boron nitride which effectually prevents metal from freezing to the surface.



We have found this technique to be particularly useful with precision casting furnaces where freezing of very hot metal onto the somewhat cooler furnace mouth was quite common and annoying. Boron nitride is a very stable compound and never dissolves in the melts.

The accompanying photograph shows a small precision casting furnace. The operator's hand is clamping a long mold over an opening in the furnace cover. The entire unit will then be tilted, transferring metal from crucible to mold. The furnace opening over which the mold is placed, has previously been covered with boron nitride. (E. EPREMIAN, research laboratory, G. E. Co.)

An Improvised Hardness Test

WHEN the services of a Rockwell or Brinell tester are not available, close determinations of the hardness of steel parts can be made by means of a vise, a steel ball from a ball bearing (approximately ½ in. in diameter), blocks of steel with known hardness values, and a Brinell microscope or other means of measuring ball impressions.

The ball is placed between smoothed surfaces of the steel with the known hardness value and that of which the hardness is to be determined, the loose assembly then being clamped between the jaws of the vise. Applying by hand as much pressure as possible in drawing the jaws of the vise together, the hard ball is pressed into both pieces of steel. The diameters of both impressions made are then measured, as with a Brinell microscope. If both impressions measure the same, the hardness readings will be approximately the same; obviously, if one impression is larger it is in the softer of the two.

By having small rectangular blocks of steel with predetermined hardnesses on hand — ranging from C-30 to C-55, a wide span of hardness determinations can be made in this manner with fairly accurate results.

The surface hardness of parts so massive that they cannot be brought to the Rockwell or Brinell machines can also be determined, approximately, and in a similar way by placing a hard ball between the smoothed surfaces of a pretested block and the piece to be tested. Then by striking the smaller piece a sharp blow with a sledge or falling tup, the indentation by the bearing is made into both pieces and a comparative measurement can then be made. (THEODORE F. BURCH, Kentucky Steel Treating Co.)

Killed Bessemer Steel for Seamless Tubes

By E. C. Wright
Asst. to President, National Tube Co.
Pittsburgh, Pa.

WHEN National Tube Co. abandoned the manufacture of lapweld pipe in 1938, the bessemer capacity used for making the skelp had little outlet. The question immediately arose as to whether it would be necessary to demolish these bessemer steel installations and replace them with openhearths, and it was decided first to find out whether seamless tubes could be made satisfactorily from bessemer steel. If so, the existing capacity could be retained and utilized with advantage.

Developments in the manufacture of openhearth and electric furnace steel for production of seamless tubes through the preceding years had clearly demonstrated that thoroughly killed or fully deoxidized steels gave much more uniform results and seamless tubes of better quality. On the other hand, previous attempts, extending over a period of 25 years, to make seamless tubes out of bessemer steel which had not been killed had almost always resulted in failure. It was therefore decided that we should attempt to produce a fully killed bessemer steel of good forging quality before making further attempts at rolling it into seamless tubes.

Preliminary work on deoxidizing bessemer steel in the ladle, using additions similar to those employed in deoxidizing low carbon openhearth heats, gave very inconsistent results. Although large amounts of silicon and aluminum were added to the ladle prior to the manganese addition, many of the heats were not thoroughly killed and they had erratic forging properties.

A survey of the physico-chemical conditions surrounding steel manufacture and deoxidation enabled us to measure the deoxidizing power and efficiency of various agents, and also emphasized the important effect of temperature upon this chemical reaction. A thorough study of the literature on the physical chemistry of steelmaking permitted us to calculate with considerable accuracy the effectiveness of the available deoxidizers. Equilibria between oxygen and other elements in liquid steel at 1600 and at 1700° C. (the results of our calculations) are shown in Fig. 1 and 2. The significant conclusion of this work was that *carbon* is a very satisfactory deoxidizer and that its efficiency is retained as the temperature of the steel is raised. Since bessemer steels at the finish of the blow are usually hotter than openhearth steels at the refining stage, the use of carbon as a partial deoxidizer appeared to be even more valuable.

The most effective means of adding carbon to a steel bath is in the form of molten pig iron. However, in order to obtain the benefit of the carbon deoxidation it is necessary to add the carbon to the blown bessemer metal before the addition of the standard deoxidizing agents such as manganese, silicon, and aluminum. Although numerous attempts had been made to blow the vessel in such a way that it could be turned down at some desired carbon content and thus retain the necessary carbon, control of this operation appeared to be impossible; it therefore became necessary to blow the vessel until the drop of the carbon flame. (The use of spectroscopes and other instruments to stop the blow at the correct point to control the carbon content was always unreliable.) As a result, the blown metal at the time the converter is turned down contains approximately 0.04% carbon, with practically no manganese or silicon remaining. The oxygen content of the blown metal is quite high at this stage.

Assuming a converter metal of the composition just given, the problem becomes one of adding the required amount of carbon, without chilling the metal, to get the carbon deoxidation reaction.

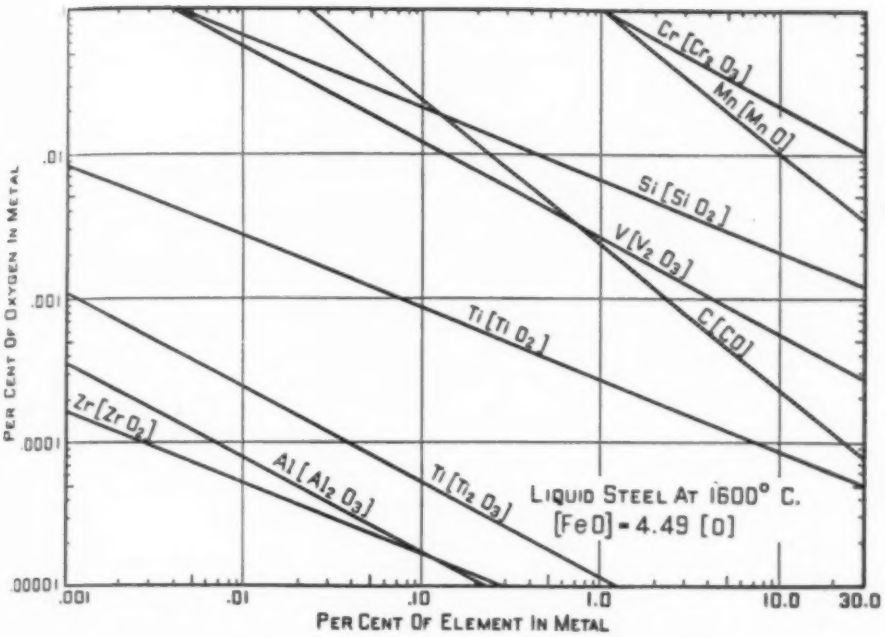


Fig. 1 — Equilibrium in Liquid Steel at 1600° C. (2910° F.)

and also enough excess to leave sufficient carbon in the steel for the desired analysis. To try this idea, various amounts of molten pig iron sufficient to give 0.20% carbon or less were added to blown converter metal, and it was soon found that approximately 0.05% carbon was consumed in deoxidizing the FeO in the bath. It is necessary to add this molten pig iron in the converter vessel, and this represents one of the difficulties of the process, since small amounts of molten pig iron varying from 400 to 2000 lb., depending on the size of the converters and the final carbon content of the steel, must be accurately measured and added in order to control the carbon reaction. Bessemer operators objected strenuously to such practices, especially in one of the plants where the converters were only of 13-ton capacity. It took several months to demonstrate to them the usefulness of the molten pig iron addition.

In making a low carbon killed bessemer heat, the procedure is therefore to blow the charge down to the carbon flame drop, add sufficient molten pig iron to the converter to produce a carbon content after mixing of approximately 0.15%, and then pour this charge into the steel ladle with the standard additions of ferromanganese, ferrosilicon, and aluminum, normally employed for thoroughly deoxidizing any heat of steel of this carbon content. In order that this practice may be clear to the reader, Table I shows the additions and efficiencies of the materials added to a 50-ton killed bessemer steel heat. Although this table represents only a low carbon heat, very satisfactory heats have been made up to 0.45% carbon, and it is now possible for our operators to produce killed bessemer heats with accurate carbon ranges anywhere between 0.10 and 0.50% carbon.

As soon as the carbon deoxidation reaction had been carefully standardized it was found that the heats so processed were very thoroughly deoxidized and could be poured into hot top ingot molds and rolled into very satisfactory seamless tubes. Etch tests on bars and tubes show a dense, fine-grained forging structure, and the yields in seamless tubes approach very closely to the yields obtained on openhearth and electric furnace steel.

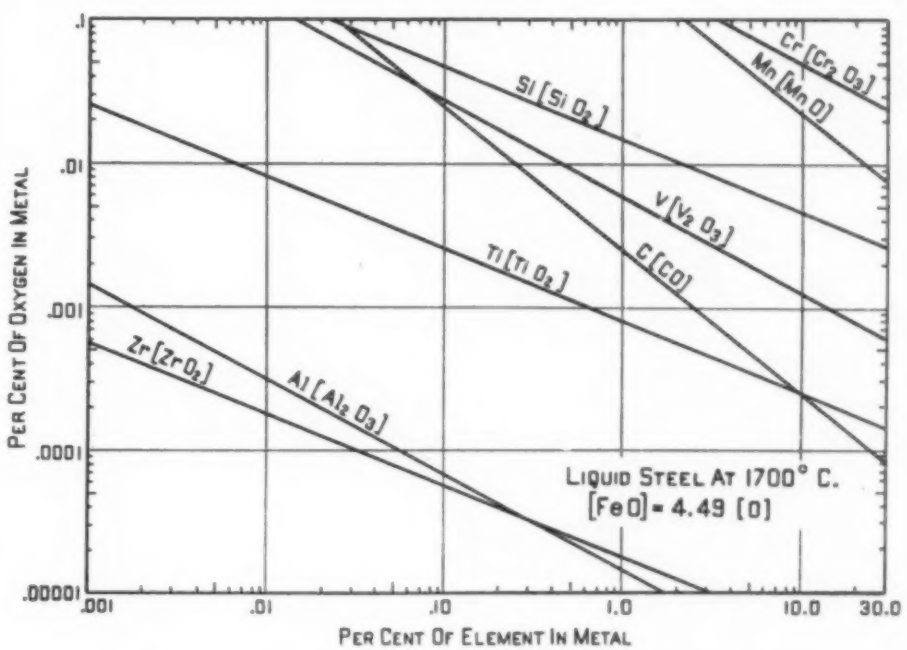


Fig. 2 — Equilibrium in Liquid Steel at 1700° C. (3090° F.)

Inclusion ratings of these heats also show clean steel, probably due to the carbon reaction and the high temperature in the ladle.

The steels made by this practice are distinctly different from openhearth steels of the same carbon and manganese content. For seamless tube manufacture it is necessary to keep the sulphur content of these bessemer steels low, preferably under 0.05%. (This is also true of openhearth steels for seamless tubes, unless the manganese be raised above 1%.) The fact that the killed bessemer steels contain considerable amounts of phosphorus and nitrogen, generally of the order of 0.09% phosphorus and 0.015% nitrogen, gives these steels high strength and good welding properties. For example, a 0.15 to 0.20% carbon killed bessemer steel will equal a 1035 openhearth steel in tensile properties.

Table I — Chemical Balance in a Killed Bessemer Heat

Element	Blown Metal 100,000 Lb.		Molten Pig 2800 Lb.		Ferromanganese 600 Lb.		Ferrosilicon 500 Lb.		Final Heat 103,900 Lb.		Addition Efficiency
	%	Lb.	%	Lb.	%	Lb.	%	Lb.	%	Lb.	%
Carbon	0.04	40	4.25	119	7.00	42	—	—	0.15	156	72.0
Silicon	0.008	8	1.50	42	—	—	48.00	240	0.21	218	74.5
Manganese	0.05	50	0.60	17	78.00	468	—	—	0.436	453	83.2
Oxygen (0.36% FeO)	0.08	80	—	—	—	—	—	—	0.015	15	

Favorable Physical Properties

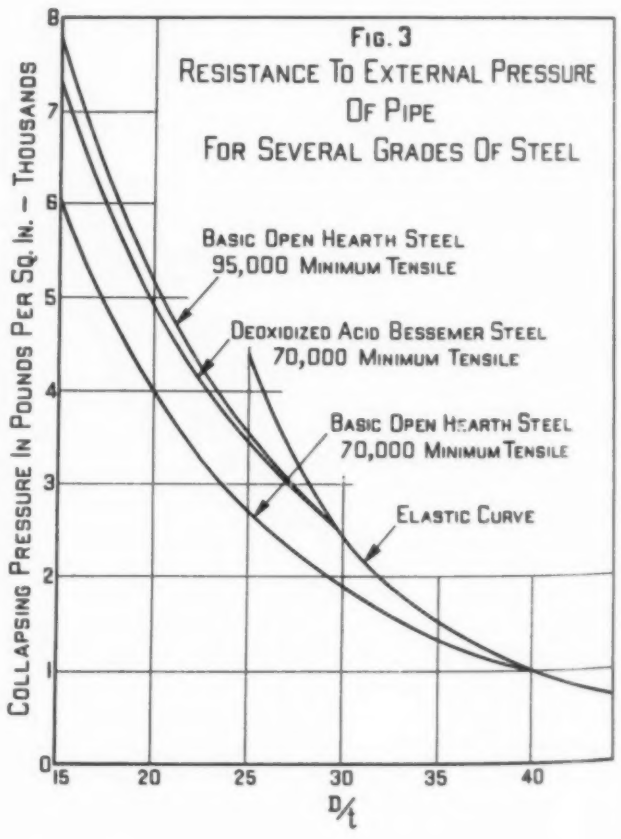
During the past seven years the physical properties of these killed bessemer steels have been quite thoroughly explored. The most significant feature from a structural standpoint is the fact that steels of high yield point and tensile strength, with good elongation, are readily made with rather low carbon contents. These steels have a particularly high elastic limit as compared to openhearth steels of the same tensile strength, and this special property has made them particularly adaptable to oil well casing which must be highly resistant to collapse — a property which is proportional to the elastic limit of the material used, rather than its tensile strength.

Expected tensile properties are as follows:

	Average	Minimum
Yield strength at 0.01% set	53,020 psi.	43,400 psi.
Yield strength at 0.2% set	55,000	45,000
Tensile strength	75,000	66,000
Elongation in 2 in.	35%	25%

Collapse resistance of the killed bessemer steels is compared to corresponding grades of openhearth steels normally used for casing in Fig. 3. The killed bessemer steels have likewise been entirely suitable for most forms of common pipe usages, and particularly for structural pipe such as is used for drive pipe, railings, masts, piling, and other pipe wherein rigidity and stiffness are desirable.

The effectiveness of this development is well demonstrated by the experience obtained during the past seven years wherein more than 800,000 tons of bessemer steel ingots have been produced, and some 500,000 tons of seamless pipe and tubing have been made in all sizes from ½ to 24 in. outside diameter.



Liquid Carburizing*

By R. S. Komarnitsky
Standard Steel Spring Co.
Coraopolis, Pa.

LIQUID carburizing is a method of impregnating steel surfaces with carbon and small amounts of nitrogen to improve strength and wear resistance. As distinguished from plain mixtures of cyanide and chlorides, liquid carburizers are used for producing deep cases of high carbon and low nitrogen content. In composition these baths differ by the presence of alkaline earths (barium, calcium and strontium) which function as catalysts to increase the rate of carbon absorption.

Carburizing activity of the bath is due to the decomposition of sodium cyanide (NaCN). In the presence of oxygen it changes into sodium cyanate (NaCNO), which in turn decomposes into sodium carbonate (Na_2CO_3), carbon monoxide (CO), and active nitrogen (N). The atomic nitrogen combines directly with the iron, while carbon monoxide is converted into carbon dioxide (CO_2) and active carbon (C) before the latter is absorbed into the case. As nitrogen interferes with carbon absorption, plain cyanide baths without catalyzers are economical only for the production of shallow, high nitrogen, low carbon cases; their depths rarely exceed 0.010 in.

The addition of alkaline earth catalysts to a cyanide bath inhibits the formation of sodium cyanate. The increased carburizing activity of the bath is attributed to the reaction

$$Ba(CN)_2 \rightarrow BaCN_2 + C$$

known as the "cyanamid shift". This becomes increasingly prominent with increasing temperature, thus liberating larger amounts of active carbon with diminishing amounts of active nitrogen. As indicated in the second paragraph, the amount of nitrogen absorbed by the steel at a given temperature is a function of the cyanate content of the bath.

The presence of nitrogen in the surface layers of the steel part, in amounts produced by liquid carburizing baths, is only beneficial as it improves the wearing properties of the case.

Operating Ranges—The economical operation range of liquid carburizing baths is 1550 to 1750° F. Below this range they produce shallow, high nitrogen, low carbon cases comparable to those obtained in plain cyanide baths. Operations above 1750° F. are not economical, due to rapid rise in costs, including maintenance of equipment, necessity of preheating the work, and critical selection of steel.

Time-Penetration Data—Baths compounded to operate within the 1550 to 1650° F. range belong to the "accelerated" or "activated" type. Operating with a cyanide content of 17 to 23% and a top cyanate limit of 1%, they produce economically carbon-nitrogen cases up to 0.030 in. deep. Typical time-penetration curves are shown in Fig. 1, page 666. Range of composition of accelerated baths is given in Table I.

"Deep-case" baths are characterized by lower cyanide content (7.5 to 12%), the presence of two catalysts, and generally higher catalyte content (see Table I). Operating within the 1600 to 1750° F. range, and with cyanide limited to 0.3%, they produce economically cases up to 0.250 in. deep. Nitrogen content of such cases diminishes with higher operating temperatures. Typical time-penetration curves are shown in Fig. 2, page 667.

Liquid carburizing offers the metallurgist the following advantages:

1. Freedom from distortion, not equaled by other carburizing methods.
2. Absence of "oxygenation" of case, often present after pack carburizing.
3. Very close but easy control of depth and characteristics of case.
4. Economy and flexibility of operation.
5. Adaptability to mechanization and mass production.

There are also certain disadvantages, such as:

1. Necessity of removing salt from the work by special means, such as hot spray washing, acid dip, or dip in bath of double salt.
2. Difficulty in keeping the installation and its surroundings spot-clean.
3. Necessity of careful disposal of cyanide-bearing wastes.

*One of the documents used by the Metals Handbook Committee in formulating the section on carburizing for the 1947 edition.

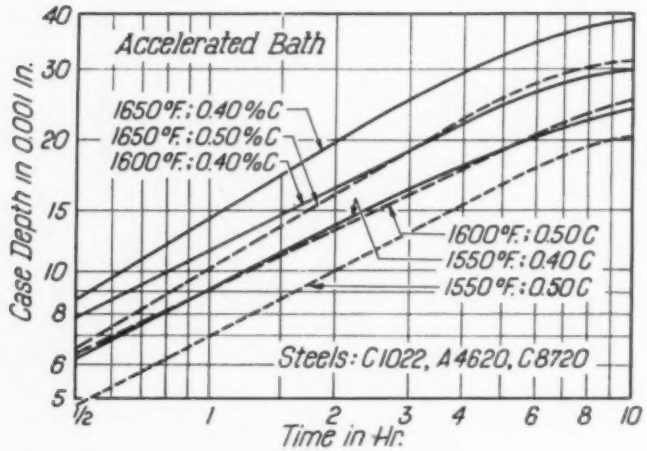


Fig. 1 — Relationship Between Time and Depth of Case Induced in Low Alloy Steels by Accelerated Baths

Control and Operation

Liquid carburizing baths are available as single mixtures, containing all the necessary ingredients, or in two components, consisting of a neutral salt base or mixture and a concentrated carburizing mixture of cyanide and alkaline earth catalysts. Control of the carburizing performance of an uncontaminated bath depends entirely upon maintaining the required concentration of cyanide within the proper cyanide-catalyte ratio. Hence the replenishment should be done not by adding concentrated cyanide or cyanide-chloride mixtures, but by adding a mixture of components containing properly balanced amounts of cyanide and catalytic salts. The drag-out losses are usually insufficient to provide room for adequate replenishment of cyanide; consequently single mixture baths are more expensive to operate as they require a larger amount of discard.

Free access of the air to the bath causes waste, as oxygen causes cyanide to decompose and generate carbon at a rate in excess of the steel's ability to absorb it. Hence the universal use of carbonaceous cover on the surface of the bath. It also performs another valuable function — a considerable reduction of radiation losses.

The amount of air available for oxygen-cyanide reaction is a prominent factor in selecting the control method. A reasonable uniformity of case may be obtained without periodic analysis for cyanide content only in continuous operation of a bath using identical charges and carburizing cycles, so that there is only a small variation in cover disturbances. In such operations periodic replenishment based upon a previously established schedule may suffice. However, analysis of cyanide content is simple and does not require full-fledged laboratory facilities, and such periodic control pays big dividends in consistency of results and economy of operation. If it is combined with metallurgical examination of case characteristics, no other chemical analyses are necessary for normally operating baths.

Failure to obtain proper depth of case at previously established carburizing cycles is attributable to *(a)* cyanide content insufficient to generate the required amount of active carbon within the time and temperature limits of the cycle; *(b)* stratification of bath, due to sludging and presence of Na_2CO_3 in excessive amount (see Table I, p. 667, for limits); *(c)* excessive NaCNO content (resulting in blocking the carbon penetration by nitrogen) either due to improper cyanide-catalyte ratio, or interference with catalytic action by contamination with silica, metal oxides, and other impurities.

Typical compositions and operating limits of liquid carburizing baths are shown in Table I.

While most of the carburizing baths utilize sodium cyanide as the active ingredient, a proprietary bath utilizing calcium cyanide has been successfully used for many years to obtain cases up to 0.030 in. It is noteworthy that the amount of $Ca(CN)_2$ in this bath is approximately 0.5% — a small percentage of the sodium cyanide required to obtain comparable results in the other types of bath. However, the necessity of using approximately 70% of calcium chloride is the most serious drawback of the calcium cyanide type of carburizing bath. Use of this highly hygroscopic salt requires special precautions to avoid rust on the work. It also adds materially to the equipment maintenance.

Liquid carburizing baths are simple to operate if certain precautions are observed.

1. **General Precautions**

(a) Carburizing salts should be stored in closed containers in a dry place to prevent absorption of moisture and consequent decomposition of cyanide.

(b) All containers should be tightly closed except when actually removing material from them.

(c) The furnace should be completely hooded and connected to an adequate exhaust system to carry away fumes of sodium carbonate. Although nonpoisonous, sodium carbonate is very irritating to the mucous membranes, and in contact with moist skin it produces irritation due to its alkalinity.

(d) Low temperature heat treating salt should be kept out of liquid carburizing baths, as it explodes on contact with molten cyanide.

(e) Dirt, dust and oxides should be kept out of the bath to prevent contamination.

2. **Starting a New Bath**

(a) Obtain and follow advice of furnace and salt manufacturers.

(b) Clean pot free of all moisture and scale.

(c) Melting in an externally heated furnace must be done gradually to prevent local overheating of the pot.

(d) A two-component bath, in an immersed electrode type of furnace, should be started by melting the neutral base component. After a sizable puddle of molten salt is obtained, replenishing mixture may be added in a ratio required to obtain the desired concentration of cyanide.

(e) Control the heat input rate by manual setting of transformer taps so as not to exceed the rated capacity of transformer (usually marked with a red line on the ammeter).

(f) Stabilize the bath for several hours at operating temperature before start of production.

3. **Operation**

(a) Fixtures and work should be completely dry before charging into the bath; moisture causes spattering.

(b) Face masks must always be worn in charging work in and out of furnace and in handling molten salts. Asbestos gloves should also be provided.

(c) To avoid possible violent expulsion of material during solidification, molten salt should not be ladled out into containers more than 6 in. deep.

(d) Formation of a carbonaceous cover is inherent in liquid carburizing baths. If this cover is inadequate a high purity natural flake graphite (silica content 1% max.) or artificial graphite powder with an ash content not over 2% should be used.

(e) A thick sludge of carbonates with heavy metallic content forms in the bath. (It consists of reduced iron oxide from work fixtures and pot, nickel and chromium from electrodes and thermocouple tubes, copper and other impurities.) Sludge should be removed periodically by scraping the bottom of the pot with suitable tools.

(f) If stop-offs are needed for selective carburizing, only high density copper plates, deposited from cyanide solutions, should be used on the surfaces to be free of carburization.

(g) A nonsaponifiable oil should be used for quenching, since drag-out salt may form soap and gum on the part, difficult to remove.

(h) Hot spray washing with emulsion type cleaners is best for removing salt from work and fixtures. To remove salt from deep recesses, the work may be dipped from 2 to 10 sec. in a 10% concentration of inhibited hydrochloric acid, followed by thorough water wash and immersion in

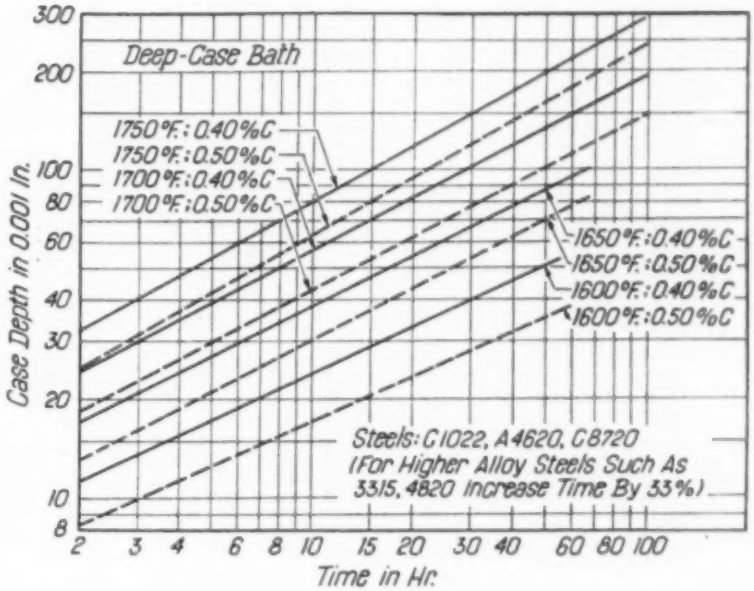


Fig. 2 — Relationship Between Time and Depth of Case Induced in Low Alloy Steels by Deep-Case Baths

Table I — Composition Ranges

	Accelerated Bath	Deep-Case Bath
Sodium cyanide	17 to 23%	7.5 to 12%
Barium chloride	15 to 40%	45 to 55%
Other alkaline earths	0 to 3.5%	2 to 10%
Potassium chloride	—	5.5 to 20%
Sodium chloride	20 to 30%	0 to 15%
Sodium carbonate	30% max.	30% max.
Sodium cyanate	1% max.	0.30% max.

warm oil or a hot alkaline bath containing 4 oz. per gal. of soda ash.

(i) It is a common practice in mass production setups to dip the work into double chloride (KCl+NaCl) salt bath to remove relatively insoluble alkaline earth compounds. This bath may also perform two other valuable functions — removal of cyanide to permit safe isothermal quench in nitrate-nitrite salt, and stabilizing work at lower temperature for quench.

4. Restarting of Frozen Bath

(a) Remelting hazards are completely avoided by the following precautions: Before the bath freezes, insert a steel wedge in the center of the bath. The tip of the wedge should touch the bottom of the pot, while the nose should protrude at least 4 in. above the salt level. Do not remove the wedge until the bath is solidified completely, as molten salt may be forcibly blown out through the created opening. Remove the wedge before remelting, after loosening by tapping it with a hammer. The space occupied by wedge will then provide a vent for entrapped gases, expanding during remelting.

(b) The above precautions are not necessary in electric furnaces with closely spaced electrodes, or in wide-spaced electrode furnaces equipped with starting coils, as such baths melt from the top downward.

Fig. 3 — Liquid Carburizing Bath With Overhead Screw Conveyor for Passing Work Through Bath. Loading, quenching, unloading of fixtures, each carrying four automotive spline shafts, is done manually

5. Safety Considerations

The possibility of cyanide poisoning is very remote if a few simple precautions are observed.* Poisoning may occur either by breathing cyanogen gas (generated if cyanide comes in contact with any acid) or by taking cyanide into the body by mouth. A less prevalent hazard is the continuous contact of cyanide with the skin, resulting occasionally in "cyanide sores". Burns from molten cyanide mixtures are the same as those from alkalis and should be treated in a similar manner.

Equipment and Fixtures

Two general types of furnaces are available for liquid carburizing; one is an externally heated pot, the other is of the immersed electrode type.

Externally heated pots are heated by oil, gas or by electric resistance coils. Special attention should be paid to furnaces of this type to obtain reasonably long life of pot and furnace: Prevent direct impingement of the flame on the pot; arrange combustion chamber to eliminate "hot spots"; seal around the edges of the pot to prevent seepage of salt into the combustion chamber. This type of furnace is suitable only for intermittent production on a small scale. The controlling factors are limitation of pot size and unsuitability for operation above 1650° F.

The development of the immersed electrode type of furnace made feasible the application of liquid carburizing to large volume production. It employs a welded rectangular pot made of low carbon boiler plate and two or more electrodes of heat resisting alloy, immersed in the bath. Heating is accomplished by virtue of the resistance the liquid salt offers to the passage of alternating current between electrodes. Current comes from one or more transformers, with secondary circuit output of 5 to 16 volts through several taps, arranged for manual adjustments for heat input rate. Temperature control (of on-off type) is by thermocouple and controlling pyrometer, which actuates magnetic switches in the primary circuit of the transformers. The thermocouples are protected by sheaths ordinarily made of

*See *Metal Progress* Data Sheet No. 60 (1946 Edition) for "Precautions Against Cyanide" prepared by the staff of E. F. Houghton & Co.

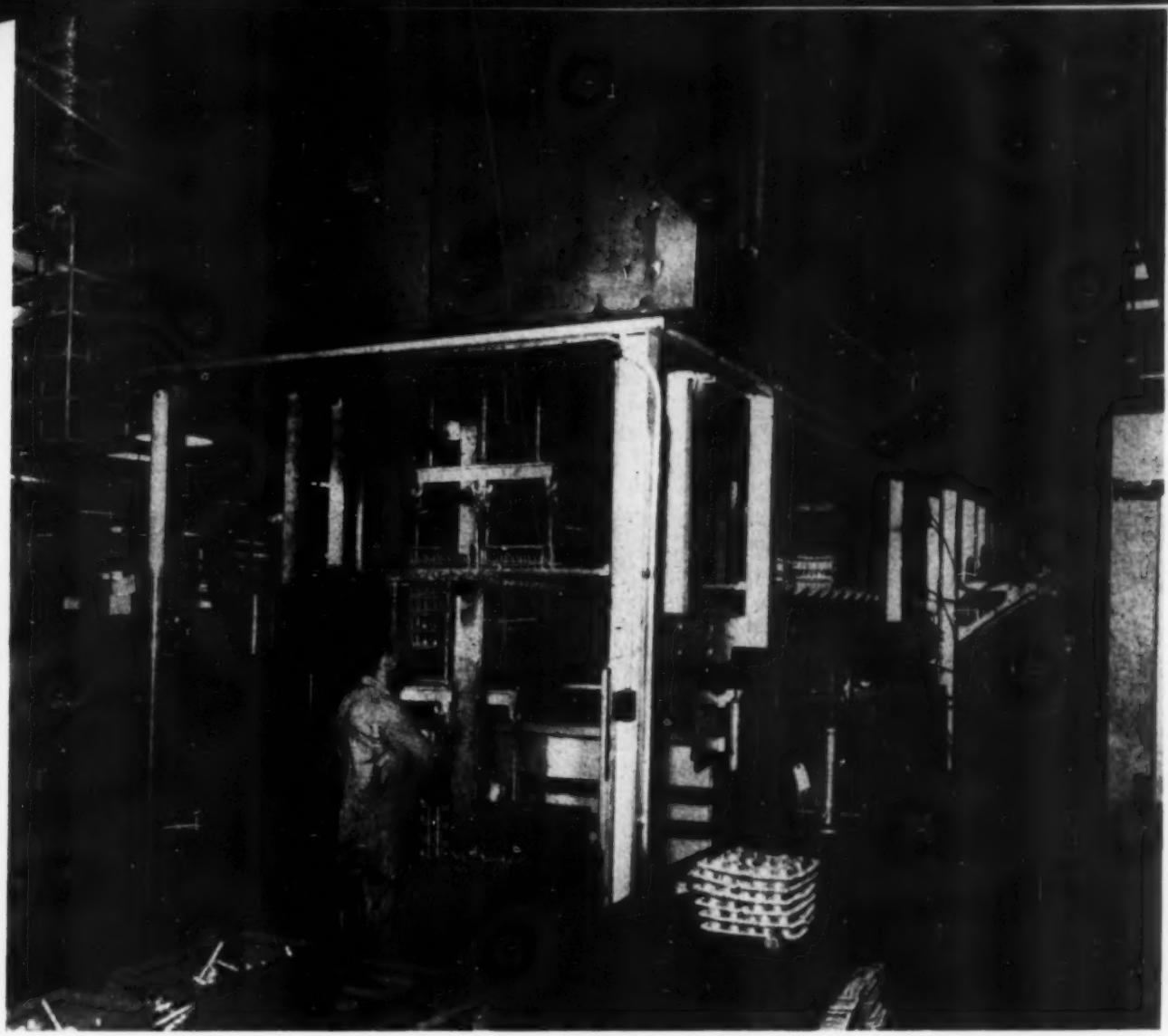


Fig. 4 — Mechanized Liquid Carburizing Unit for Hardening Refrigerator Parts. The work is carried through carburizing bath at 1750, a cleaning bath at 1450, a water quench, a tempering bath at 350°F., followed by wash and rinse. Conveying mechanism returns work overhead to loading station. Courtesy of Ajax Electric Co.

Inconel, and sometimes of pure nickel. It is advisable to install an additional indicating thermocouple for each controlling one, for quick detection of controlling thermocouple failure.

If salt, even in minute quantities, drops into the gap between the outer wall of the pot and the insulating brick in the furnace setting, progressive corrosion of the outer surface of pot will occur. An increased volume of corrosion products will bulge the pot's walls inward and lead to premature failure. If precautions are well taken care of, eventual pot failure will occur at a considerably later date by corrosion perforation of the wall at the salt level. This corrosion is retarded by frequently removing deposits of decomposition products on the walls of the pot. This precaution should also apply to electrodes.

Baskets, racks and fixtures for handling work are usually made either from heat resisting alloys of chromium and nickel (20-25 Cr-Ni min.) or Inconel. Welded structures of rolled shapes last longer than castings. If the installation has a high ratio of salt volume to work, and if fixture distortion is of little importance, welded low carbon steel fixtures are often economical. Careful design of handling fixtures and quenching systems is necessary to obtain the full benefit of freedom from distortion offered by liquid carburizing.

Handling of the work ranges from charging in-and-out, small individual furnaces by hand, to entirely mechanized production setups performing automatically all operations from charging to washing and drying the carburized and quenched parts. Three general methods are used in mechanization: *(a)* the screw conveyer, *(b)* the "jack-rabbit" conveyer, and *(c)* a circular arrangement of pots with the work conveyed by a centrally located "merry-go-round".

By adaptation of any of the above methods or combinations of same, a great number of effects can be obtained, limited only by the ingenuity of the designers.

Our Biographical Dictionary

Richard Sebastian Read

Dean of Electric Furnace Steel Melters

THE LATE Dr. JOHN A. MATHEWS has said that the era of our modern steel expansion began in 1874 — steel nails, barbed wire, tinplate, the first steel bridge, all appeared in America. That was the year DICK READ was born. Therefore, during his lifetime the steel industry has grown from comparative infancy to what it is today. He has seen the annual steel production in the United States increase from less than 4,000,000 tons to over 90,000,000. The capacity for electrically melted steel today is greater than that of crucible, openhearth and bessemer combined in 1889.

RICHARD SEBASTIAN READ comes from a family of steelworkers — rollers, melters, puddlers. His grandfather, SEBASTIAN NEVERGOLD, was a roller at Singer-Nimick Works in Pittsburgh for 35 years. DICK's father, RICHARD J. READ, worked for NEVERGOLD at Singer-Nimick, and in 1873 went to the Canton Steel Co. at Canton, Ohio, eventually becoming superintendent of the openhearth. DICK at 15 began working for *his* father, and when his father died, six years later, DICK was made superintendent — quite a responsibility for a young man of 21, even in those times when boys took on men's work.

Crucible Steel Co. of America later acquired the Canton Steel Co. and transferred the most desirable orders to the Pittsburgh plants. Therefore, in 1903 DICK left Canton and went to work for the Vulcan Crucible Steel Co.

The following year, R. H. BULLEY, who had owned a goodly portion of the Canton Steel Co., teamed up with C. HERBERT HALCOMB (who had been in charge of Sanderson Brothers Steel Co. at Syracuse and later president of the newly formed Crucible Steel Co. of America) and projected the Halcomb Steel Co. in Syracuse, now the Halcomb Works of Crucible Steel. The plant was to make high grade steels — mostly toolsteels — and in addition to the usual crucible melting furnaces, hammers, rolls, heating furnaces, annealing furnaces and wire mill, there was at first contemplated a stationary openhearth furnace. DICK was called from Vulcan by Mr. BULLEY (February 1905) to draw up the plans and to operate this furnace, based on his experience at Canton, but shortly after this the plans were changed.

Early in 1905, READ met Dr. PAUL HEROULT, the French designer of and the holder of patents issued in 1886 covering an "arc resistance electric furnace". Experience in France had indicated the possibilities of this furnace for fine steelmaking, and the infant Halcomb company, taking a long chance, purchased a furnace from Dr. HEROULT, and persuaded him to forward to the United States the shell of a single-phase three-ton furnace then building. This furnace became Halcomb furnace "Number One". Dr. HEROULT's original idea was to use the electric furnace simply for deoxidation and the removal of sulphur, as he had obtained a process patent in the United States which called for melting and dephosphorizing in a tilting openhearth furnace where a continuous bath was maintained. Molten metal was to be taken from this reservoir furnace and charged into the electric furnace where the heat was duplexed.

Accordingly, a 20-ton tilting openhearth was installed at Halcomb by Wellman-Seaver-Morgan. As a source of power for the electric furnace, a special General Electric generator with high amperage and low voltage (500 kva.) had to be designed and built; it was driven by a McIntosh-Seymour cross-compound engine. The original automatic electrode regulator was a Thury. This furnace was the first commercially operated, electrically heated steel melting furnace in the western hemisphere. Therefore, this year, 1946, is the 40th anniversary of American electric steel.

The first heat was made on April 5, 1906, and was a cold melt, straight carbon toolsteel — Heat No. 1-D-6. This historic heat was scrapped because something went wrong with the mechanical equipment and there was not enough power available to obtain the desired temperature, but even at that the phosphorus was 0.032 and the sulphur 0.025%.

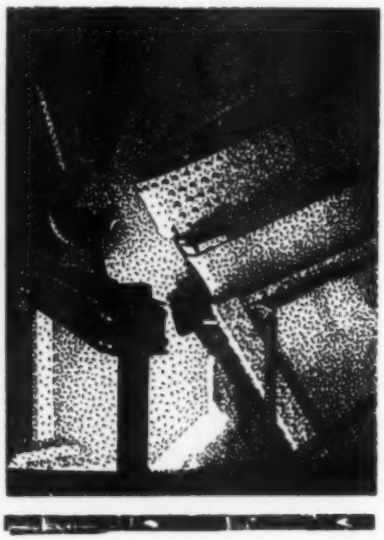
The second, third and fourth heats were also cold melt, straight carbon toolsteel heats, and in these heats, the phosphorus and sulphur ran 0.021 and 0.022%, 0.020 and 0.030%, 0.018 and 0.025% respectively. Twenty years later, specimens of these heats were subjected to modern metallurgical inspection and measured up to carbon toolsteel standards.

From then on, the heats were duplexed and the openhearth under DICK READ delivered its first metal to old "Number One" on April 12, 1906. Heat 5-D-6 showed phosphorus 0.013% and sulphur 0.022%. Heat 15-D-6 showed phosphorus 0.014% and sulphur 0.016%. Every good tradition of crucible melting practice was carried over to the new electric furnace process. By 1907, operations were under the supervision of Halcomb's own melters. The openhearth continued to deliver hot metal until about 1920.

(This openhearth also made "shot" for use as a base in the crucible melting furnaces. It was a

sight never to be forgotten to see a ladle, filled with 20 tons of molten metal, suspended from a crane, move slowly up and down the length of a 25,000-gal. concrete tank filled with water and to see the hot metal run from the ladle into a graphite pot — suspended from the ladle — with holes through sides and bottom and into that water tank.)

From April to December 1909, READ was at the South Chicago Works of Illinois Steel Co., where a three-phase 15-ton Heroult was being broken in. He then returned to Halcomb's electric furnace department, where he has been ever since.



In the beginning, old "Number One" was really a problem. There were no spares for any of the European-built parts and when something went wrong, the furnace shut down until a replacement could be made or the part rebuilt. For example, at the 25th heat, a large worm gear on the tilting mechanism broke.

By 1909, "Number One" was melting alloy steels to supply a better product for the then rapidly expanding automobile industry. Nickel steel (3½% nickel), chromium-vanadium steels and chromium-nickel steels appear on the Halcomb melting record in March and April 1909, bearing steels in 1910, tungsten magnet steel in 1911, Krupp chromium-nickel in 1914, chromium magnet in 1915, and high chromium stainless in 1919.

Furnace roofs were always a source of great trouble. At first, the roof was only 16 in. high at the arch and 7 in. at the skewback. That was hard not only on roofs but also on the bottoms, as the silica from the melting roof bricks would drip into the basic slag, upsetting the balance there and cutting the basic banks and bottom. Eventually, the roof was raised until it was 24 in. at the arch and 14 at the skewback. DICK's efforts along this line resulted in an increase in the average roof life from 20 heats to well over 100.

Hot top ingot molds were used from the beginning. These hot tops were heated hot (and still are) before being placed on the ingot molds. Tapered ingots were also first cast from steel from this furnace in 1909, the usual ingot size being 8x9, or 8x9½ in. Electrodes were 15¾ in. quarter octagon, and the waste stub was as much as 50 in. long. This, of course, was corrected with the advent of the round threaded electrode and nipple, making it possible to add an electrode to the portion in use and avoid the stub discard.

Old "Number One" now stands on a concrete pedestal in Bulley park, a little triangular grassy plot at the office building. "It could still be melting steel," said READ to a recent visitor.

While the electric furnace of itself was not a cure-all, READ realized it would prove an excellent medium for control purposes and for the recovery of alloys formerly lost entirely or in part in the openhearth furnace. In 1925, he made the first approach to a hardenability control in carbon toolsteel and shortly thereafter was its master.

He still maintains his fracture tests and, of course, all of his life has battled with slits, hairlines, inclusions, and the other diseases inherent to the melting furnace and the ingot mold.

RICHARD READ married KATHERINE C. PRICE at Canton, Ohio, and they have three daughters, ELIZABETH, MARGARET and JULIA, all university graduates. MARGARET lives with her parents in their fine three-story home near the Drumlins at Syracuse's eastern edge. Those Drumlins are glacial hillocks over which Syracuse golfers play in summer, and Syracuse youngsters sled in winter. No sportsman, DICK READ at 72 takes his pleasure by simply motoring with Mrs. READ throughout the countryside.

READ is a charter member of the Syracuse Chapter ASM, and past president of the Electric Metal Makers Guild.

To his subordinates, DICK READ is an inspiration, a leader and a teacher, never a boss. Quiet, soft spoken, unhurried, he can be exemplified by any one of his casting crews. From the craneman in the cage to the melter on the floor, from the stopper man to the man who heats the hot tops and places them on the ingots, teamwork is like clockwork — perfect coordination.

His character as a supervisor is to be gaged by his prize remark: "The Company makes the good steel; I make the bad." Thus, to his coworkers he gives complete and absolute cooperation.

He never forgets the fundamentals. With all of our scientific advances, with all of our knowledge gained, with every help and aid available, the metallurgy of steel while at very high temperature is still clouded by many unknowns. High grade steel melting is still an art requiring artists — and the dean of these artists is RICHARD S. READ.

HOWARD J. STAGG

Correspondence

Copper Plate as a Stop-Off When Nitriding

DETROIT, MICH.

To the Readers of METAL PROGRESS:

In his letter in the April 1946 issue, C. J. Miller lists information of interest on stop-off materials when nitriding, which supplements that published by the undersigned in the February 1945 and December 1945 issues of *Metal Progress*.

In comparing his work with that done by us, Miller apparently overlooks the significant difference that his data were obtained for a 65-hr. nitriding cycle while the data submitted by us were obtained for a 154-hr. cycle, with a few runs being made for longer periods. He found that for a 65-hr. cycle the *kind* of plate was relatively unimportant. This may be true for such a short cycle but it is not borne out by our experience when using a cycle as long as 154 hr.

On the production job from which the authors' data were obtained, cyanide copper deposits and also bronze deposits gave poor results — in fact the excessive number of failures in the nitriding furnace which resulted when these deposits were used led directly to our study.

Regarding Mr. Miller's comments about sandblasted surfaces — we did not say that sand blasting did not improve the plate distribution. We did find that a heavier over-all plate was required to protect a sandblasted surface than was required to protect surfaces finished by machining or grinding. The data given in our letter in the December 1945 issue of *Metal Progress* apparently are supported by Miller's data — that is, in general the rougher the surface the heavier the copper deposit must be to be effective.

W. V. STERNBERGER
Chief Metallurgist and
Motor Products Corp.

E. R. FAHY
Chemical Engineer
United Chromium, Inc.

Doggonit

KALISPELL, MONT.

To the Readers of METAL PROGRESS:

On reaching this western retreat, and unpacking things for walking, riding, fishing, hunting, I find a photograph of a spotted setter (maybe part Dalmatian) on point — my dog Hadfield. He

was originally photographed (500 diameters) at Battelle Memorial Institute, where he materialized as a group of oxide and sulphide inclusions in a piece of medium carbon, high manganese cast steel.

JOHN A. FINLEY

A Fable for Atom Busters

BOSTON, MASS.

To the Readers of METAL PROGRESS:

In view of the many recent editorial comments on atomic fission I thought this Indian fable might be of as much interest to others as it was to me. I happened upon it in "The Wisdom of China and India", edited by Lin Yutang and published in 1942 by Random House; and was struck by its timelessness and timeliness. Alter a few words in the final verse and it is far from antiquated!

DOROTHY K. SPENCER

The Lion Makers

In a certain town were four Brahmans who lived in friendship. Three of them had reached the far shore of all scholarship, but lacked sense. The other found scholarship distasteful; he had nothing but sense.

One day they met for consultation. "What is the use of attainments," said they, "if one does not travel, win the favor of kings, and acquire money? Whatever we do, let us all travel."

But when they had gone a little way, the eldest of them said: "One of us, the fourth, is a dullard, having nothing but sense. Now nobody gains the favorable attention of kings by simple sense without scholarship.

Therefore we will not share our earnings with him. Let him turn back and go home."

Then the second said: "My intelligent friend, you lack scholarship. Please go home." But the third said: "No, no. This is no way to behave. For we have played together since we were little boys. Come along, my noble friend. You shall have a share of the money we earn."

With this agreement they continued their journey, and in a forest they found the bones of a dead lion. Thereupon one of them said: "A good opportunity to test the ripeness of our scholarship. Here lies some kind of creature, dead. Let us bring it to life by means of the scholarship we have honestly won."

Then the first said: "I know how to assemble the skeleton." The second said: "I can supply skin, flesh, and blood." The third said: "I can give it life."

So the first assembled the skeleton, the second provided skin, flesh, and blood. But while the third was intent on giving the breath of life, the man of sense advised against it, remarking: "This is a lion. If you bring him to life, he will kill every one of us."

"You simpleton!" said the other, "it is not I who will reduce scholarship to a nullity." "In that case," came the reply, "wait a moment, while I climb this convenient tree."

When this had been done, the lion was brought to life, rose up, and killed all three. But the man of sense, after the lion had gone elsewhere, climbed down and went home.

And that is why I say:

Scholarship is less than sense;
Therefore seek intelligence:
Senseless scholars in their pride
Made a lion; then they died.

Subsurface Nucleus of Failure

WILLIAMSPORT, PA.

To the Readers of METAL PROGRESS:

We thought you might be interested in the valve spring failure illustrated, a photograph of the fractured surface at about 15 diameters. The arrow points to a small hole just beneath the surface which was the nucleus of the failure. Fatigue rings can be seen emanating from this hole (which was almost spherical in shape). What puzzled us was how this spherical hole could be present in the finished part after the material had been subjected to all the mechanical working during the process of cold drawing and other manufacture. The hole may likely have been filled with refractory material or a spherical inclusion which dropped out upon failure. At any rate this is the most striking example of subsurface failure that we have seen.

R. D. ZONGE
Chief Metallurgist
Lycoming Division, The Aviation Corp.

The Bailey Bridge

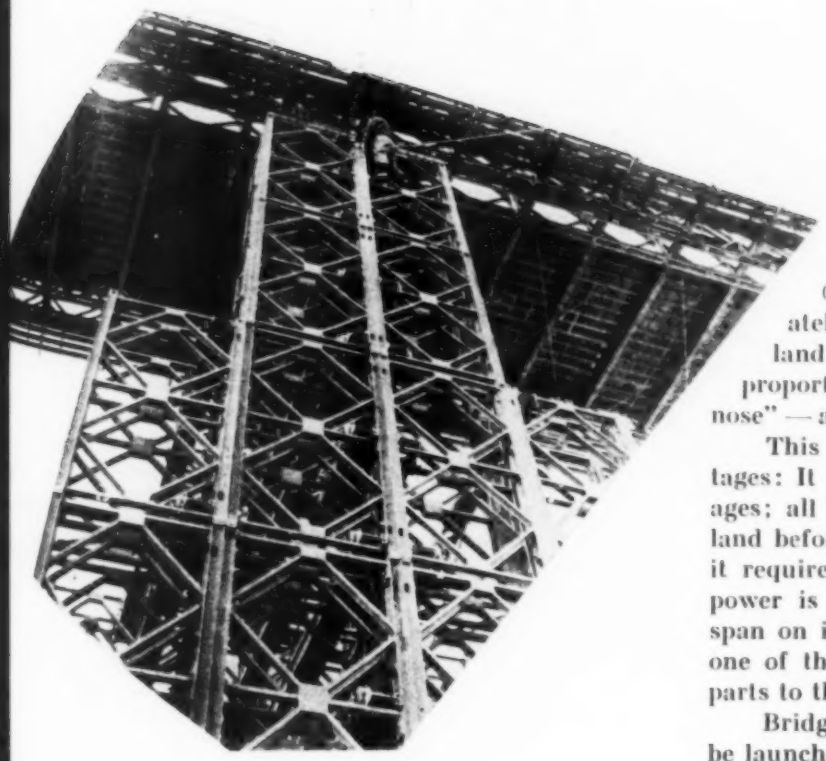
LONDON, ENGLAND

To the Readers of METAL PROGRESS:

Many references have been made to the great help which allied troops received, during the invasion of Italy and later in the campaign in northern France, from the standardized bridge unit known as the Bailey Bridge, but little published about the engineering details. The bridge itself was christened for Donald Coleman Bailey, civilian chief designer of Britain's War Office Experimental Bridging Establishment. The idea was in his mind for some years, but detailed development was not started until late in January 1941; the prototype was tested and the design put into production on July 2 of that year. Speed was necessary because existing types of bridging could carry no more than 27 tons, and the Churchill tank then being designed was expected to weigh somewhere between 45 and 50 tons.

The basic principle was to be a through type of bridge of two main girders. These girders would be built up of panels, the design being so arranged that an indefinite number could be placed end to end, one, two, three or more trusses built up of prefabricated panels could be placed side by side, and two or more stories could be erected above each other. This produced girders of variable strength which the designers felt had provided an answer for any future flights of fancy on the part of tank or mobile gun designers. The through girder allows a minimum construction depth and a roadway near the level of the bottom chord, while the presence of the main girders at each side gives the vehicle drivers a sense of safety.

Tolerances were kept as generous as possible to utilize the capacity of innumerable small firms of the "garage" type which had lost their businesses owing to the war but had small workshops containing a few machine tools and welders.



"Skyline" Bridge Across the Albert Canal in Holland, Utilizing Bailey Units for a Pier, 50 Ft. High

The basis of the design was that a double truss, double story bridge should carry a 50-ton tank over a span of 120 ft. The units of the bridge would also have to be loaded in standard trucks. These requirements produced a panel approximately 10 ft. long and 5 ft. high weighing 570 lb., and it was decided that no part of the bridge should be heavier than this — that is, a six-man load. The panel was an all-welded structure in the form of four K's facing alternate directions.

One of the heaviest parts of all military bridges of this type is invariably the cross-girders which carry the deck. These were therefore spaced at 5-ft. intervals instead of the usual 10 ft. At the same time arrangements were made to double them when the bridge was required to carry extra heavy loads. This close spacing in turn enabled 2-in. timber decking to be used.

Another most important feature of the design was the simplification of all connections. Panels were designed with male and female jaws at their corners, and the joint was made by the insertion of a single pin at each corner to lock them together. The principle adopted for all minor connections was that the load should be taken by a single tapered dowel engaging in a socket in the opposite member. This dowel was held in engagement by a small bolt and nut which passed through its center. The taper on the dowel in combination with the pull of the bolt was an effective method of aligning the two parts during assembly. Since the bolt takes no load itself, it was possible to arrange its dimensions so that only two spanners could erect the whole structure.

The bridge is erected on the roadbed at the near abutment. As it is erected it is pushed forward on rollers (the bottom chord having been deliberately kept smooth). Three panels are on land while two are overhanging space; this proportion is maintained until the "launching nose" — a dummy prolongation — reaches land.

This method of launching has many advantages: It requires the construction of no anchorages; all bridge assembly can take place on dry land before any part is pushed out over the gap; it requires no derricks, ropes or tackles, and if power is required to assist in pushing a heavy span on its rollers, this is readily available from one of the trucks which has brought the bridge parts to the site.

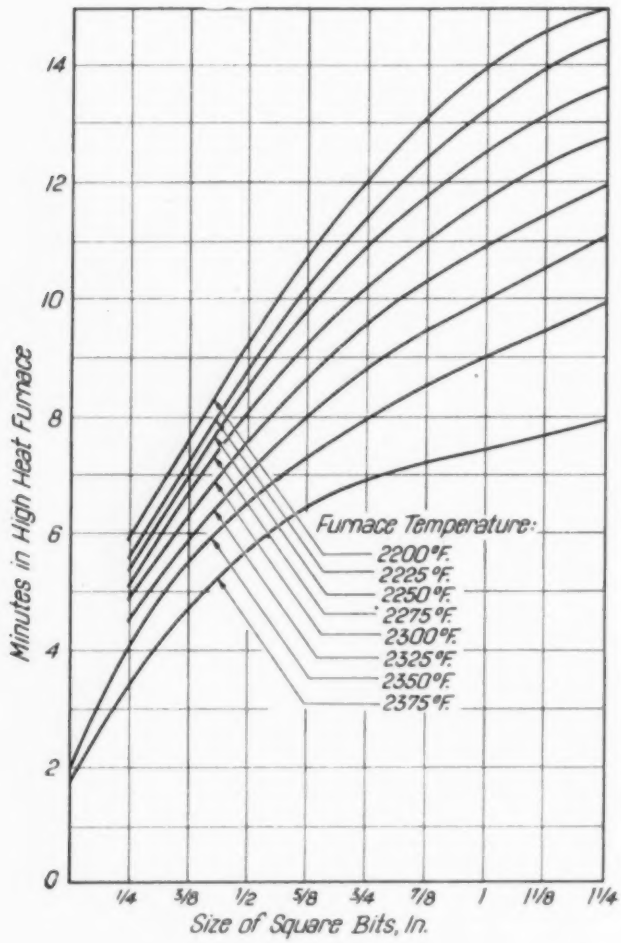
Bridges up to about 120-ft. span can generally be launched by man power.

Once the design was accepted production grew quickly to an extremely high rate. The design lent itself to accurate jigging, but there was an acute shortage of skilled welders, so there were many early problems arising out of the employment of semiskilled operators. Apart from the normal engineering concerns, such firms as garages, metal window makers, bedstead makers — even confectioners — were all turning out parts. An elaborate system of gages had to be rapidly devised to insure interchangeability of components made by such a variety of firms. The basic 120-ft. bridge contains approximately 70 tons of steel, made up of 31,000 detail pieces, and requires more than 3 miles of weld.

Over 200 miles of fixed bridge and 40 miles of floating bridge were manufactured in Britain, and over 600 firms were employed on the job. Peak production reached 22,500 tons (approximately 8 miles of bridge) a month. The planned rate of production was maintained despite German air raids, flying bombs and rockets.

In the United States the components were redesigned to suit American rolled sections, particular care being taken to make the parts interchangeable with British. Owing to the quantities already made it was only necessary for American production to reach about 10% of the British. The American unit was constructed of high tensile, low alloy (nickel-copper) steel with tensile strengths between limits of 63,000 and 70,000 psi.

S. A. Stewart, (Col.)
Deputy Director
Royal Engineer Equipment



Timing High Speed Tools in High Heat

NICETOWN, PHILADELPHIA

To the Readers of METAL PROGRESS:

Here are some curves we have successfully used for several years for timing high speed steel of various sections in the high heat furnace after a 1600° preheat. We use muffle furnaces, and the data are for them. A shorter time than that shown would probably be sufficient in a salt bath. We have no information as to the latter point; perhaps other readers knowing the facts would be willing to publish them.

A. A. BRADD
Asst. Supt. of Research, The Midvale Co.

Salt Baths for 18-8

DUNDAS, ONT.

To the Readers of METAL PROGRESS:

Keith Whitcomb's article in the August issue on "Salt Baths for Heat Treating 18-8" brings forth some questions and comment:

The use of molten sodium carbonate as an austenitizing medium makes one wonder how much decarburization is noticed and what effect it has, beneficial or otherwise, on the corrosion resistance of heat treated parts. It would seem that such a bath would be quite unsuited for the hardenable types of stainless.

In our shop we have not found that the straight barium chloride baths give off any chlorine when new. They give off a very little fume at 1850° F. and can be rectified by immersed graphitic carbon rods. Our experience is confined, however, to refractory brick pots and submerged electrodes. It would be interesting to know what type of pot is best for sodium carbonate.

To one who has experienced posthardening corrosion caused by chloride baths the use of sodium carbonate seems like a worthwhile innovation when decarburization is not a factor.

L. F. TRAIN
Metallurgical Engineer
Pratt and Witney of Canada

Shot-Peening of Springs

TURIN, ITALY

To the Readers of METAL PROGRESS:

All informed metallurgists and materials engineers know that shot-peening is a very useful method for increasing the endurance of machine elements whose working surface stresses in tension approach the safe limit. However, some items in recent literature make rather large claims for the process — one statement being that shot-peening increased the life of springs up to 1000%. In my opinion this was too optimistic, far exceeding our records of service experience, so I had some tests made on spring materials of various surface conditions and springs of various types.

0.177-in. dia. spring wire, oil tempered, would endure an average of 224 alternate torsions to 180° as received. Samples cut from the same coil, shot-peened with round steel shot, withstood 292 torsions, an increase of 30%. There was no difference in the ultimate tensile strength of the wire, before and after shot-peening.

Heavy helical springs for knee action suspensions (centerless ground rods) showed a 25% increase in fatigue life. Automobile leaf springs are improved much more; their fatigue life in our standardized test increases from 100 to 125%.

(In this treatment we use round steel shot, about 0.020-in. diameter, thrown in an air blast of 45 psi., with nozzle 12 in. from the spring.)

In general we find that shot-peening is of greater benefit in pieces working in bending or under flexural stresses than in pieces working in torsion; also that pieces with smooth surfaces are benefited less than pieces with such surfaces as left after hot rolling or forging.

ALBERTO OREFFICE
Chief Engineer, Steel Dept., The Fiat Co.

It's the ***FINAL COST*** *that counts*

...keep it low with non-ferrous ***NICKEL*** *alloys*

CUPRO-NICKEL

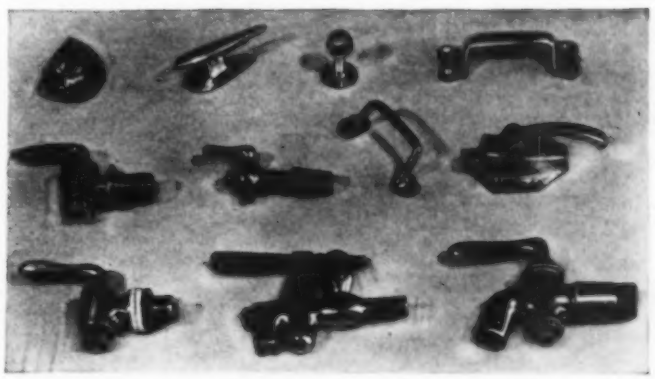
No Tube Deterioration Indicated after 6 Years of Service

In these feedwater heaters, thin tube walls of .065 gage Cupro-Nickel permit high and rapid heat transfer at working pressures up to 900 pounds p.s.i. Hairpin bend U-tube units of ⅝" O.D. Anaconda Cupro-Nickel Tubes indicate no deterioration after serving 6 years. Characterized by high strength at operating temperatures, along with sturdy resistance to erosion and corrosion, Cupro-Nickel renders economies in applications throughout industry . . . just as it does in these heaters built by Struthers Wells Corp.

NICKEL SILVER

A Metal Combining Beauty with Practical Durability

The beauty of solid Nickel Silver impresses one instantly. Essentially white in color, Nickel Silver possesses strength as well as corrosion-resistant properties superior to the usual brasses. It is a metal that may be cast and worked by simple methods. Available in extruded, rolled, drawn and cast sections, this Nickel alloy lends itself to countless applications. A few items produced by the National Brass Works of Los Angeles, Calif. in 20 percent Nickel Silver, are shown at right.



NICKEL-BRONZE

A Little NICKEL Imparts Strength and Toughness

Only 2 percent of Nickel gives these gear rim blanks and transformer case castings what they need. Nickel improves the strength of standard bronzes and is particularly effective in raising elastic properties . . . increasing shock-resistance as much as 25 to 50 percent. Moreover, Nickel increases castability . . . thus it helps to reduce losses due to mis-runs and affords a widened casting range. The photograph shows Nickel-Bronze castings produced by the Philadelphia Bronze & Brass Corp.

EMBLEM OF SERVICE INCO Nickel

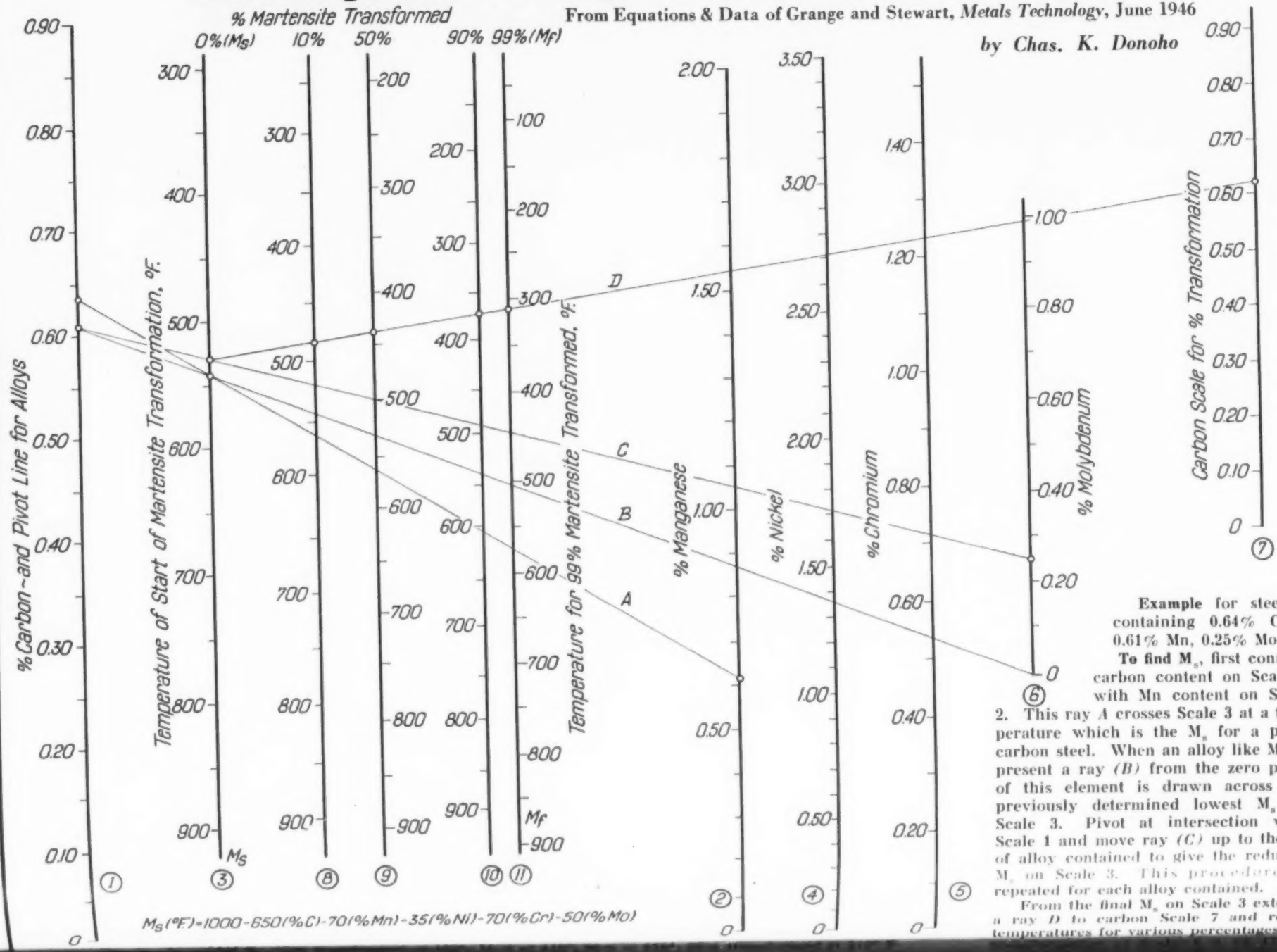
Over the years, International Nickel has accumulated a fund of useful information on the selection, fabrication, treatment and performance of alloys containing Nickel. This information and data are yours for the asking. Write for "List A" of available publications.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N.Y.

The Temperature Range of Martensite Formation

From Equations & Data of Grange and Stewart, *Metals Technology*, June 1946

by Chas. K. Donoho



Example for steel containing 0.64% C, 0.61% Mn, 0.25% Mo:

To find M_s, first connect carbon content on Scale 1 with Mn content on Scale 2. This ray *A* crosses Scale 3 at a temperature which is the M_s for a plain carbon steel. When an alloy like Mo is present a ray *(B)* from the zero point of this element is drawn across the previously determined lowest M_s on Scale 3. Pivot at intersection with Scale 1 and move ray *(C)* up to the % of alloy contained to give the reduced M_s on Scale 3. This procedure is repeated for each alloy contained.

From the final M_s on Scale 3 extend a ray *D* to carbon Scale 7 and read temperatures for various percentages of

By Robert S. Archer
Climax Molybdenum Co.
New York City
Past President ⊖

Boron in Steel

IT IS NOW well established that the hardenability of many steels can be markedly increased by the addition of extremely small amounts of boron, an element which is available in the United States in unlimited quantities as far as any possible requirements of the steel industry are concerned. These facts suggest that boron can be used to replace some of the strategic alloy elements where these elements are used for hardenability.

Boron is introduced into steel in the form of various ferroalloys added in the ingot molds or, preferably, in the ladle. Four of these ferroalloys will be mentioned, without any implication that they are the only ones available or likely to become available. A ferroboron containing about 11% boron is marketed by the Molybdenum Corp. of America. The Electro Metallurgical Corp. also markets a ferroboron, and in addition a complex alloy called Silcaz which contains about 0.5% boron. The Vanadium Corp. of America markets another complex alloy called Grainal which also contains about 0.5% boron. The Titanium Alloy Mfg. Co. has an alloy Bortam containing 1 to 2% boron. More will be said about these alloys later in this report. [Others have appeared since 1942.]

Boron can also be introduced into steel by the addition of borax to the ladle or ingot mold, especially if a suitable reducing agent is mixed with the borax. Anhydrous borax or "borax glass" contains about 20% of the element boron. The use of ferroboron has certain advantages over that of borax, which is mentioned because it is believed to be feasible and because it offers an unlimited source of boron as far as the purpose here under consideration is concerned.

The complex alloys mentioned above contain important amounts of elements other than iron and boron. Their manufacturers and many users consider that they improve steel to a greater degree than boron alone. In this report the complex alloys are considered because they offer means of adding boron to steel. This does not imply in the least that the other ingredients are not valuable, nor even that boron is the most valuable ingredient of any particular complex alloy mentioned.

Determination of Boron — Satisfactory wet methods are available for the determination of boron in ferroalloys made to contain this element, in which the boron content will usually be over 0.10%. The same methods will also yield results having some degree of accuracy on cast irons or experimental steels containing down to about 0.01 or 0.02% boron, the percentage of error increasing as the boron content decreases. When boron is added to steel to increase hardenability, the amount *added* is nearly always less than 0.01%, and is usually between 0.001 and 0.005% of the weight of the steel. Work has been done and is still in progress on the determination of boron in these small amounts by wet methods, but results cannot yet be considered satisfactory.*

Boron in these minute amounts can be detected by the spectroscope, and it is considered in a few laboratories that results are being obtained which are accurate enough to be useful — although still not as accurate as desired. The problem has not even been approached of determining whether any boron present is in an oxidized or unoxidized form or otherwise chemically combined.

It is thus seen that most of the laboratories in the country, whether at steel plants or at consumers' plants, are unprepared to determine boron or even to detect its presence in steel in the amounts here under consideration. This is an important obstacle in developing the manufacture

*EDITOR'S NOTE — This statement is as of 1942. Since then procedures for determining accurately small amounts of boron in steel by both chemical and spectrographic methods have been developed in government and commercial laboratories. The National Bureau of Standards has issued a series of spectrographic standard samples of boron-treated steels covering the range from 0.0006 to 0.019% boron, as well as a chemical standard containing 0.0027% boron. Grange has also shown that if a steel containing boron is transformed isothermally, a precipitate appears at the prior austenite grain boundaries, and this is a way of detecting boron-treated steels.

EDITOR'S NOTE: As all American metallurgists know, a shortage in the ordinary alloying elements for ordinary steels was anticipated early in the war. Readers of *Metal Progress* have been informed about the various expedients adopted to meet the changing conditions imposed by the demands of the Army and Navy, and the chemical, explosive and artificial rubber industries. Among the possibilities was the use of the very powerful hardener, boron. Its potentialities were but dimly appreciated in the early years of the war, and continuing investigations have been financed by various governmental agencies. *Metal Progress* hopes to publish full summaries of all this work. As a start, this first installment is a summary of the knowledge existing as of late 1942, and consists of very full extracts of a "Report on Boron in Steel by the War Metallurgy Committee of the National Academy of Sciences", written by Robert S. Archer, chairman of the Subcommittee on Boron in Steel, and at that time chief metallurgist of the Chicago District of Republic Steel Corp. The document's official designation is O.S.R.D. No. 973, Serial M-18.

and use of boron-treated steels. It is not necessarily, however, an insuperable obstacle. It may be pointed out, for example, that the manufacture and use of steels made "fine grained" by ladle additions of aluminum was developed without much attempt to determine the amount or form of the aluminum retained in the steel; in this case, determination of the austenitic grain size developed at a specified temperature proved sufficient for most practical purposes.

Recovery From Scrap

In the case just mentioned the problem was greatly simplified by the known fact that any unoxidized aluminum in scrap, pig iron or ferroalloys charged into the steel melting furnace is substantially eliminated during the melting process. If aluminum were retained, any regular production of "coarse grained" steels would now be almost impossible, and "fine grained" steels would often contain more aluminum than desired.

(The elimination of aluminum from the raw materials charged into a steel refining furnace is, of course, due to its high affinity for oxygen, which causes it to be oxidized by air or by almost any other oxide present in the slag.)

It seems that boron is not nearly so strong a reducing agent and that it is in fact rather easily reduced into steel from its own oxide. If boron is to be added in the ladle, it is desirable and perhaps necessary to know how much boron, if any, is present in the steel as it is tapped into the ladle. Otherwise the final product is apt to contain either more or less boron than is desired, and if boron is recovered from scrap, then any large-scale use of boron would eventually make it impossible to produce boron-free steel except by using only virgin materials in the charge.

There seems to be very little positive information regarding this question. This is partly due to the fact that much of the work on boron in steel has been done on a small scale, involving induction furnace heats or ingot mold additions, and partly to the general lack of means for the determining of small amounts of boron. In the case of cast iron containing 0.05% boron, Mr. Tisdale of the Molybdenum Corp. of America states that about half of the contained boron is recovered on remelting in a cupola. Here, although the conditions are oxidizing to some extent, they are much less so than in an openhearth furnace, and there are larger amounts of carbon and silicon in the metal — which may protect the boron from oxidation. Furthermore, the small amount of slag present in cupola melting is more acid than in the basic steel melting processes.

Inquiries among various steel producers who have experimented with boron have failed to discover any real attempt to determine whether boron is recovered from scrap in the basic openhearth process. Two heats of S.A.E. 1045 were made in which substantial amounts of boron-treated scrap formed part of the charge. In neither heat did the resulting steel exhibit any abnormal hardenability, which fact was taken to indicate that any boron recovered was not enough to affect this property appreciably. These two experiments are, of course, far from being adequate to answer the general question. The Molybdenum Corp. reports indications that boron is not recovered in steels containing up to 1.0% carbon.

Summing up, the meager information indicates that there is a substantial recovery of boron on remelting cast iron scrap in a cupola, and no appreciable recovery of boron from boron-treated *steel* scrap in making steels of less than about 0.50% carbon in a basic openhearth furnace. Appreciable recovery of boron might occur in making high carbon steels in the basic openhearth, or in acid melting, or in electric furnace melting with single slag practice.

Historical

Most of the experimental work in this country on the use of small amounts of boron (0.001 to 0.01%) in steel has been done within the last few years, and much of it within the past year. This suggests that the effectiveness of such additions was previously unknown, but this is not true. One early disclosure is contained in U. S. Patent 1,519,388 filed August 13, 1921 and issued December 16, 1924, to Richard Walter of Düsseldorf, Germany, from which the following is quoted:

> "Many attempts have been made to improve iron and steel and their alloys by adding boron thereto, but the results so far were not encouraging for the reason that the amount of boron used, generally from 0.2 to 2%, is altogether too high and renders the product too hard and brittle; and of late the experiments with boron in this connection have practically been abandoned .... If a minimum of 0.007 up to a maximum of 0.01% of boron is added to steel, it will produce a self hardening steel .... CLAIM 1: A carbon-bearing alloy, with iron as the predominant element, having incorporated therein a boron content within the limits of 0.001 and 0.1%."

It seems very likely that information such as that disclosed by Walter led to experiments in some steel plants at about that time. If so, nothing seems to have come of it in the way of regular production of steels recognized as boron-treated.

One of the causes of the comparatively recent resumption of interest in boron was the introduction a few years ago by the Vanadium Corp. of America of a series of ferroalloys called "Grainal". The original Grainal, later known as No. 1, had the following nominal composition: 10% Al, 15% Ti, 3% Si, 25% V. Experiments by various steel producers showed that the addition of about 4 lb. per ton of this alloy to certain steels (in the mold or ladle) increased hardenability to an extent which might be called unexpected, in that the same results could not generally be obtained by the addition of mixtures containing equivalent amounts of the four elements listed above. Analysis of various samples of Grainal disclosed boron contents around 0.25%, and the Vanadium Corp. has stated that boron is present in No. 1 Grainal to the extent of about 0.15 to 0.30%. Assuming a boron content of 0.25%, the addition of 4 lb. per ton is equivalent to the addition of 0.01 lb. of boron per ton or 0.0005% of the weight of the steel. Whether or not the presence of this very small amount of boron had anything to do with the effect of No. 1 Grainal, knowledge of its presence at least had something to do with a resumption of interest in boron.

The Molybdenum Corp. of America put on the market a ferroboron containing 11% boron, and recommended the addition of an amount equivalent to about 0.003% boron in the steel.

The Electro Metallurgical Corp. which had on the market two complex ferroalloys of the deoxidizing type known as Silvaz and Silcaz, also brought out modifications of these alloys containing 0.5% boron, stating that the incorporation of boron was for the purpose of increasing hardenability. The initial recommendation was to add 4 lb. of ferroalloy per ton of steel in the mold or 7 lb. in the ladle. These additions are equivalent to 0.001 and 0.00175% boron respectively. It is now reported by one steel producer that the addition of 4 lb. per ton in the ladle is effective in a certain grade of strongly deoxidized steel.

Another cause of the current interest is that hardenability is now much more generally recognized than formerly as a basic criterion in the selection of steels which are to be used in the heat treated condition. Along with this recognition have come a clearer conception of what hardenability means, and a considerable degree of standardization of testing procedure.

Within the past year or two in particular, actual or threatened shortages of the strategic alloys have greatly increased the interest in boron or any other readily available material which offers promise of conserving the older conventional alloys.

These very brief and far from exhaustive historical notes are intended to assist in obtaining a perspective of the present state of the art.

Hardenability

The term "hardenability" has been used somewhat loosely in describing the ability of steel to harden on quenching from above the critical temperature range. The *intensity* of hardening or degree of hardness attainable is determined by the carbon content of the steel, in the case of the plain carbon and common alloy grades. The *ease* of attaining this maximum or martensitic hardness is affected by the carbon content but is also greatly affected by the presence of the various alloy elements, such as manganese, chromium and molybdenum. Such elements, including carbon itself, decrease the cooling rate necessary to fully harden the steel. Thus it is necessary to use higher alloy content when it is desired to quench a piece of given size in oil instead of water, or when the size of the section to be quenched is increased.

As is well known, a measure of hardenability is had by the standardized Jominy or end-quench

test, now widely used by the American industry.*

Next to the composition of the austenite, the most important factor known to affect hardenability is the grain size of that austenite at the time of quenching. When quenching is not quite rapid enough to prevent transformation to products softer than martensite, such transformation tends to begin at grain boundaries and progress throughout the grains. A fine-grained structure (A.S.T.M. grain size No. 5 to 8) presents more boundary surface for nucleation than a coarse-grained structure (A.S.T.M. grain size No. 1 to 5), and shorter distances for propagation. The fine-grained steel is, therefore, more readily transformed to the softer products, such as pearlite, and thus has less hardenability.

Effect of Boron on Coarsening

The addition of boron to steel tends to lower the grain-coarsening temperature of the austenite and thus increase the grain size established by heating for a given time at a given temperature.

Example: Heat A; S.A.E. 1045

Ladle addition of aluminum sufficient for fine grain. Boron added in two ingot molds in form of 11% ferroboron.

Ingot No.	Boron Added	McQuaid-Ehn Grain Size — Core	Quench Grain Size 40 Min. at 1525°
16	None	7	9
11	0.0016%	Not rated	8
13	0.0032	5 to 7	7

Example: Heat B; S.A.E. 1045

Ladle addition of aluminum for fine grain. Boron added in three ingot molds as 11% ferroboron.

Ingot No.	Boron Added	McQuaid-Ehn Core	Quench Grain Size 1460°	1525°	1600°	1750°
15	None	5 to 6	7	7	6	6
13	0.003%	1 to 5	6	6	2 to 5	2 to 5
14	0.0045	1 to 4	7	5	2 to 5	2 to 5
16	0.0075	0 to 4	6	5	2 to 4	2 to 4

It is, of course, impossible to cite here enough specific examples to tell the whole story about grain size, so conclusions will be given which are based on work done in various plants and research laboratories.

Assume that a heat of basic openhearth steel is deoxidized with silicon and aluminum in such a way that the McQuaid-Ehn grain size would normally be fine, and that boron alone is added in amounts from about 0.002 to 0.010%. Agreement is almost universal that there will be some coarsening of the grain. Some report a gradual and rather uniform coarsening amounting to one or two "frames" or grain size numbers; that is, if an average grain size of 6 was expected without the boron addition, the average grain size after the boron addition would be 4 or 5. Others report that instead of a uniform coarsening, the effect of the boron addition is often "duplexing" or the occurrence of mixed grain sizes such as 2 to 7. These coarsening effects are especially noticeable in the core of the McQuaid-Ehn specimen, and often are not noticeable in the hypereutectoid zone of the carburized case. At the lower temperatures commonly used in commercial hardening, such as 1550° F., these same boron-treated steels usually exhibit fine grain, that is, 5 to 8, but frequently *not* so fine as that of similar steels without the addition of boron.

It is to be noted that the above statements refer to the effect of the addition of boron *alone*. The statements are so qualified because it may be possible to overcome the coarsening effect of boron by other additions. When boron is added in the form of the various complex ferroalloys it is not necessary to add so much boron. In addition, these alloys contain other grain-refining agents, such as titanium, zirconium or vanadium. In general, these complex alloys produce fine grain when added in the amounts recommended by their manufacturers to well deoxidized steels.

It is of interest that for years large amounts of ferrovanadium have been used which contained about 0.2% boron. Vanadium content was about 38% or approximately 200 times the boron content. Addition of 0.20% vanadium, as in the S.A.E. 6100 steels, would thus add about 0.001% boron, and the 6100 series steels produced commercially have nearly always been fine grained.

It is not established that the addition of extra aluminum will overcome the grain coarsening effect of boron; there are, in fact, indications that extra aluminum will *not* do so.

Rightly or wrongly, most steels to be heat treated are now specified to be either coarse-grained or fine-grained. Fine grain is most commonly called for, and the basis of acceptance is usually the McQuaid-Ehn test. There is, however, a recent tendency to accept steels on the basis of grain size established by heating at 50° above the

*Hardenability is not the only criterion in the selection of steels for heat treated parts. Other properties are obviously involved, such as toughness, machinability, high temperature strength, and the like. It may be said, however, that while hardenability is not a sufficient criterion, it is at least a necessary criterion. If the steel will not harden adequately, it cannot be used. If it does harden adequately, there is at least a possibility of successful use.

normal hardening temperature, if the steels are not to be quenched directly from the carburizing temperature.

Some steel producers may know how to consistently produce steels treated with enough boron "alone" to increase hardenability substantially and at the same time meet specifications, rigidly interpreted, calling for fine grain as judged by the McQuaid-Ehn test. It is at least questionable whether this knowledge is general among all steel producers. The effective use of boron alone may therefore require either further development work on a plant scale in some of the steel mills, or some modification of acceptance standards by certain consumers.

This matter of grain size should not prove to be a serious obstacle, and the problem is not believed to be involved at all when the complex alloys are used, except rarely when a consumer might ask for coarse-grained steel.

Effect of Boron on Hardenability

There is no doubt that the addition of boron substantially increases the hardenability of many steels. Since boron also frequently coarsens the austenite grains, the question may properly be raised whether the observed increases in hardenability are not due entirely to the grain coarsening. There seems to be enough evidence that this is not the case:

1. The effect of grain size on hardenability is well known from experience. The maximum increase in hardenability from boron additions is well above that to be expected from observed differences in grain size.

2. In some experiments there have been marked increases in hardenability from boron additions without coarsening of the grain.

3. When the grain size at a given temperature is coarser in steel from a boron-treated ingot than in steel from an untreated ingot of the same heat, substantially equal grain size can be produced by heating the untreated steel to a higher temperature. The hardenability of the boron-treated steel will then still be the greater.

A complete and quantitative study of the effect of boron on hardenability would involve vast numbers of tests on all of the common grades of steel, involving additions of varying amounts of boron under various conditions. No such program is near completion. It is quite possible that boron cannot be used effectively at all in some grades of steel. Enough tests have been made, however, to show that substantially increased hardenability can be obtained in many grades; a few examples will be cited for illustration.

The first example is the same Heat A of basic openhearth, fine-grained 1045 mentioned above. Its complete analysis is 0.48% C, 0.79% Mn, 0.019% P, 0.028% S, 0.23% Si, 0.15% Cu, 0.12% Ni, and 0.07% Cr.

Additions were made in various ingot molds as follows:

Ingot No.	Material Added	Equivalent to
16	None	.....
9	11% ferroboron	0.0004% B
10	11% ferroboron	0.0008% B
11	11% ferroboron	0.0016% B
12	11% ferroboron	0.0024% B
13	11% ferroboron	0.0032% B
14	No. 1 Grainal	2 lb. per ton
15	(V-bearing)	4 lb. per ton
17	85% ferrosilicon	0.20% Si
18	Low C ferrochromium	0.25% Cr
20	Ferrovanadium	0.05% V

Jominy hardenability tests were run on samples from middle billets, and as-quenched grain sizes were determined by examination of the air-cooled ends of the Jominy specimens.

Jominy test results are often expressed in abbreviated form by merely recording the distance from the water-cooled end to which a certain specified hardness is maintained. For medium carbon steels this specified hardness is often Rockwell C-50. In the following table the figures under the heading "H" are the distances from the water-cooled end measured in sixteenths of an inch (a common practice) at which the hardness has just fallen to C-50: A larger value for "H" corresponds to greater hardenability.

		Jominy Test — 1600° F.	
Ingot No.	Addition	"H"	Grain Size
16	None	2.4	9
9	0.0004 B	2.7	9
10	0.0008 B	3.0	8 to 9
11	0.0016 B	3.1	8 to 9
12	0.0024 B	3.2	8
13	0.0032 B	3.5	7
14	2 lb. Grainal	4.5	7 to 8
15	4 lb. Grainal	6.3	9
17	0.20 Si	2.8	8
18	0.25 Cr	3.4	7 to 8
20	0.05 V	3.2	8 to 9

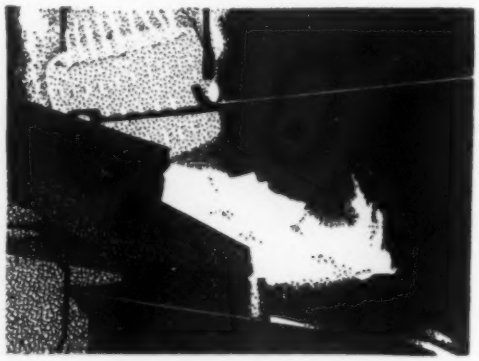
In this experiment hardenability continued to increase with boron up to the maximum amount added which was 0.0032%. Still greater hardenability was obtained with No. 1 Grainal containing some vanadium. This is in agreement with many other results which show that the hardenability obtainable with boron alone is not so great as that obtainable with the complex ferroalloys containing both boron and vanadium.

The hardenability increase obtained with 0.0032% boron in the above experiment is not

quite the maximum obtainable with boron alone, as shown in the following example from Heat B (already mentioned). It also was a basic open-hearth heat of fine-grained 1045. Its complete analysis was 0.47% C, 0.86% Mn, 0.020% P, 0.032% S, 0.21% Si, 0.13% Cu, 0.11% Ni and 0.04% Cr. Boron was added in certain molds as 11% ferroboron. "H" distances and grain sizes are:

Ingot		Jominy Tests							
		1460°		1525°		1600°		1750°	
No.	Addition	H	G.S.	H	G.S.	H	G.S.	H	G.S.
15	None	2.2	7	2.2	7	2.4	6	2.5	6
13	0.0032 B	2.3	6	2.6	6	3.1	2/5	4.3	2/5
14	0.0048 B	3.2	7	4.5	5	5.3	2/5	5.8	2/5
16	0.0080 B	3.4	6	4.5	5	5.0	2/4	5.3	2/4

In this example the highest hardenability values are accompanied by grain coarsening. Grossmann* has published the results of experiments showing the effect of boron on the hardenability of steels containing about 0.62% carbon and 0.90% manganese. Maximum hardenability was obtained with mold additions of 0.0025% boron, and slightly less hardenability was obtained with larger additions.



General experience is to the effect that hardenability increases with the amount of boron added until a maximum value is reached, after which larger additions cause either little change in hardenability or a slight decrease.

Various investigators have arrived at different values for the amount of boron which must be added to produce maximum hardenability. There is evidence from various sources that this most effective amount varies greatly with the state of deoxidation of the steel. A poorly deoxidized steel may require as much as 0.0075% boron while an addition of 0.001 to 0.0015% may suffice for a strongly deoxidized steel. It appears that this may constitute one of the most important considerations in the development of a uniformly successful practice. The effect of state of oxidation probably accounts largely for the observation that the optimum addition of boron for a large openhearth heat may differ materially from the optimum addition for a small induction furnace heat.†

*"Hardenability Calculations From Chemical Composition", M. A. Grossmann, *Metals Technology*, A.I.M.E., June 1942 (*Transactions*, A.I.M.E., Vol. 150).

†Some investigators believe that nitrogen content must be controlled and at a minimum if uniform results are to be achieved with boron additions.—Editor's Note.

Alloy Conservation

Grossmann has given a method for estimating the contribution to hardenability of any amount of the common alloy elements, including boron. His results indicate that the maximum diameter of a round bar which can just be hardened clear through (as judged by fracture or etch) is increased 1.48 times by the addition of the most effective amount of boron. However, it is not possible to state that a given amount of one alloy element is equivalent to some other definite amount of another alloy element, because the effect of a given addition of any element decreases as the amount of that element already in the steel increases. In the present state of the art (1942), the certainty of obtaining the anticipated results is greater for the commonly used alloying elements than for boron. The possible savings indicated should, therefore, be discounted somewhat. It would be fairly conservative to say that it should be possible to reduce manganese by about 20 to 25 points in steels normally containing 0.70 to 1.00% manganese, or that equivalent reductions could be made in other alloys, insofar as the attainment of hardenability is concerned. While it is impossible to predict at this time the total savings of strategic alloys through the use of boron, it should be sufficient to say that the prospective savings are substantial and important.

These conclusions refer to the savings that may be realized by the use of boron alone. It is quite possible that still greater savings may be realized by the use of a complex alloy containing other important ingredients in addition to boron.

"Fading" of Boron Effect

When boron is added to the ladle, the effect as measured by hardenability tends to decrease or "fade" toward the last ingot poured. This has been observed, for example, in 1035 steel with ladle additions of 0.002 and 0.0025%, and in 1045 steel with an addition of 0.002% boron. The first ingots poured showed distinctly increased hardenability while the last ingots poured had values as low or nearly as low as those of the same grade of steel without any addition of boron. This change during pouring may be due to a gradual

loss of boron, or to a change in form (such as oxidation). It is well known that there is frequently a loss of the strongly deoxidizing elements, such as silicon and aluminum, toward the end of a heat, presumably because of the oxidizing action of the slag in the ladle. It will be recalled that the amount of boron that has to be added to obtain maximum hardenability increases as the steel becomes more highly oxidized.

If hardenability were the only property of importance, it would apparently be a fairly simple matter to compensate for this fading effect by adding an excess of boron. For example, another heat of 1045 was made with 0.0075% boron added in the ladle, and samples from the first, middle and last ingots were quite uniform with respect to hardenability. Unfortunately, excessive amounts of boron have certain undesirable effects, including the promotion of brittleness and hot shortness.

The fading effect is mentioned here because it constitutes a problem in steelmaking which requires consideration. Some mills have already developed practices for certain grades of steel which give sufficiently satisfactory results, using either ferroboron or one of the complex alloys.

Effect of Boron on Physical Properties

Yield Point and Tensile Strength — Misleading data have been published which might lead some to conclude that the tensile strength of certain steels can be greatly increased by the addition of boron or a ferroalloy containing boron. In most steels the tensile strength in psi. is approximately equal to 500 times the Brinell hardness number. Thus, a test bar heat treated to a uniform hardness throughout of 200 Brinell will have a tensile strength of about 100,000 psi., while at 400 Brinell the strength is about 200,000 psi., and so on.

Suppose we heat treat, in the form of a ¾-in. round bar, an ordinary 1040 steel of such hardenability that the depth of hardening in a water quench is only ⅛ in. The outer ⅛ will have a Rockwell hardness of about C-60 after quenching and the structure will be martensitic, but the central portion or core of the bar will be much softer and will have a structure consisting of troostite or sorbite (fine pearlites) and ferrite. If we temper the hardened bar at a fixed temperature or to a fixed surface hardness, machine to a 0.505-in. diameter specimen and test in tension, we will be testing only that part of the original ¾-in. bar which did not harden in quenching.

Next, suppose that boron or a special ferroalloy was added to another ingot of the same heat. The hardenability might readily be increased enough so that a ¾-in. bar will harden to a martensitic structure throughout. Our 0.505-in. tensile specimen will then have properties characteristic of a uniform tempered martensite. With a given heat treatment we may thus obtain a tensile strength of say 140,000 psi. for the untreated steel and 240,000 psi. for the steel treated with boron or one of the special ferroalloys.

If we had selected a ⅜-in. round for heat treatment, both steels would have hardened throughout and would have had similar tensile properties. Likewise if we had selected a larger size, such as 1½ in., both steels would have failed to harden near the center and both would have had similar but inferior tensile properties.

Hot Shortness — It does not take much boron to make steel so hot short that it completely disintegrates in rolling. Apparently a fusible material is formed at the grain boundaries which causes the grains to separate from each other when hot working is attempted. As in the case of hardenability, various reports do not agree exactly regarding the amount of boron required to produce hot shortness. Molybdenum Corp. of America has recommended the addition of 0.003% boron for hardenability and stated that 0.006% is apt to cause hot shortness. Others have added up to 0.01 and even 0.015%, and rolled the steel into billets and bars without trouble.

Even after being successfully rolled, however, steels with these higher boron additions have sometimes shown tendencies toward hot shortness in forging. Specifically, in drawing down a billet to a bar under a hammer, bursts have been observed on the end of the piece in the central part of the section. This is not known to have been observed with boron additions of 0.007% or less.

Probably the type of steel to which boron is added has something to do with boron recovery and with the amount of boron than can be *added* without hot shortness. In fully killed steels, it seems that the boron addition should be kept below 0.007; the exact figure is not very important because the addition should be kept considerably lower in order to avoid brittleness.

In general, it seems that hot shortness is not encountered until the boron addition exceeds about twice the amount required for the maximum increase in hardenability. It would, therefore, seem that forging difficulties need not be encountered at all, but in actual practice it is probable that through error enough boron would occasionally be added to cause a heat of steel to be scrapped on account of hot shortness. This should not happen very often. It is to be noted that when one of the complex alloys is used, the boron addition is usually under 0.002%, and therefore far below the amount that causes hot shortness.

Toughness — A more serious matter is that a smaller excess of boron over the optimum amount causes brittleness. It would be fortunate if brittleness and subnormal ductility were encountered only in steel that is also hot short, since the hot working operation would then automatically reject steel lacking in toughness, but this is not the case.

The greatest degree of brittleness in the boron-treated steels which can be hot rolled is found together with an intergranular network of a rather hard boron constituent whose exact nature is not known. (The Molybdenum Corp.'s reports indicate that the constituent is $Fe_2B \cdot Fe_3C$.) Its occurrence is favored by slow cooling from the rolling or forging temperature. If the steel is then heat treated at normal temperatures, the network remains and the steel has little toughness as measured by elongation and reduction of area, or by notched-bar (so-called "impact") tests.

Experimentally, the formation of a network can sometimes be prevented in such material by cooling rapidly from the forging temperature. After heat treating at normal temperatures, the boron constituent may then be found in spheroidized form with no visible grain boundary lines. In this condition the steel is still decidedly lacking in toughness. Perhaps there are thin films of boron constituent at the boundaries which have escaped detection under the microscope.

Photo courtesy Carnegie-Illinois Steel Corp.

With a still smaller excess of added boron, and no boron constituent detected under the microscope, erratic values for ductility have been obtained. For example, when conditions are such that 16% elongation and 50% reduction of area should be obtained, the values may be 11% and 30%, respectively. Such subnormal values seem most likely to occur when the hardened steel is tempered at temperatures below 900° F.

When the amount of boron added is just barely enough for maximum hardenability, or is less than this amount, ductility and toughness are usually about normal for the tensile strength involved after proper heat treatment. Under certain special conditions toughness values greater than usual have been obtained.

In speaking of the optimum amount of added boron for maximum hardenability in the above discussion, reference is to steels with normal deoxidation for fine grain. In the medium carbon steels, such deoxidation would include the addition of about 0.15 to 0.30% silicon and 1 to 2 lb. per ton of aluminum. Maximum hardenability might then be obtained with an addition of 0.003% boron, and erratic toughness with 0.004 or 0.005%. If the same steel were more strongly deoxidized, maximum hardenability might be obtained with as little as 0.001% boron.

Low ductility has not been reported for boron additions less than 0.003%, and when one of the complex ferroalloys is used in the amounts recommended by the manufacturer, the addition of boron is usually well under 0.002%.

Hardness As-Rolled — It has been stated that boron does not increase the hardness of steel in either the as-rolled or normalized condition. This is substantially true when steels of rather low hardenability are involved, such as 1045, and may prove to be a very favorable circumstance since superior hardening characteristics may be obtained without detriment to certain fabricating operations such as machining. If the steel to which the boron is added is one of initially higher hardenability (a 0.45% carbon alloy steel, for example), then boron may substantially increase the as-rolled or normalized hardness.

Steelmaking Processes

Unless otherwise stated, the discussion in this report refers only to steels made by the basic openhearth process. More than half of the alloy steel and nearly all of the carbon steel to be heat treated is so made. The only other process involved to an important extent is the basic elec-

tric arc furnace process. It seems that most of the experimental work on boron and the boron-containing ferroalloys has been done on basic openhearth steel, except for very small induction furnace heats.

Various steel producers have made and put into use for certain special applications full heats of steel made in a normal manner except for the addition of boron. Many heats have also been used which were treated with some one of the complex alloys. There has not yet been — in 1942 — any widespread or general use in this country of steels treated with boron.

Ladle Versus Mold Addition — There has been no serious thought of adding boron in the basic openhearth furnace, and it is believed that all additions have been made either in the ladle or in ingot molds during pouring. Mold additions have been favored in much of the experimental work because this method seems to offer comparisons between ingots which are substantially identical except for the addition of boron, and because the work can be done on part of the steel made in a normal manner in a large furnace without the risk of losing an entire heat.

In general, the results obtained by mold additions seem to have checked fairly closely with those obtained by ladle additions. In several experiments with mold additions, however, specimens from various parts of an ingot (top, middle and bottom for example) have given very discordant results, indicating incomplete mixing. Other ingots have shown a high degree of uniformity. This is only to be expected; it is general experience that uniformity can be obtained by mold additions only when the addition is made properly and the amount of material added is not excessive.

In the regular production of tonnage steel, mold additions of anything so effective as boron are undesirable for both producer and consumer. It is quite a problem to make sure that the correct amount of the specified material is added to each ingot and still more of a problem to make sure that the addition is properly made. Under the best circumstances, mold additions are apt to cause dirty steel with poor surface.

To overcome the fading effect of boron toward the end of the heat, it has been proposed that *(a)* all additions be made in the molds, or *(b)* compensating additions be made to the last few ingots of the heat. This would apply either to boron or to one of the complex alloys. It is pointed out that aluminum is commonly added to the last few ingots of fine-grained heats to make up for the loss of aluminum by oxidation and the consequent tendency to revert to coarse grain. This practice is reasonably satisfactory, but it is to be noted that the amount of aluminum *added* is very small in comparison with the *total* addition of aluminum, and also that the effect of a small excess of aluminum on the properties of the steel is not appreciable.

*The Specification Problem**

In this country steels are specified, purchased, produced and distributed chiefly on the basis of chemical composition and, if they are to be heat treated, of grain size. It is true that such specifications are sometimes supplemented by certain physical requirements, such as hardenability or tensile properties, or even notched-bar impact properties, but the basis of the specification is still the chemical composition. Standardization and reduction in the number of types have been considered important objectives by the steel industry, and efforts in this direction have been based on chemical composition.

Under these circumstances any general production of boron-treated steels raises a very definite problem. How are such steels to be specified and on what basis are they to be inspected and accepted? In the first place, there is (as of 1942) no generally available method for determining or even detecting boron. Secondly, even if there were such a method, the determination of the total boron content of a steel might not suffice to decide whether the desired effect had been obtained.† It seems that the control of boron-treated steels must depend for the present largely upon tests for physical properties, including especially hardenability and toughness. Toughness tests should probably include notched-bar impact tests at low temperatures‡ at least until low temperature properties are well established. It also seems more important than usual to make sure that these properties are uniform as well as satisfactory throughout the entire heat or lot of steel under consideration.

One of the problems already confronting the

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*Editor's Footnotes — The specification problem was discussed in detail by Henry T. Chandler in "Alloy Steel or Alloy-Treated Steel (?)", *Metal Progress*, Nov. 1945, p. 1104.

†This doubt has been resolved by R. A. Grange and T. M. Garvey's paper in *Transactions* (Vol. 37), entitled "Factors Affecting the Hardenability of Boron-Treated Steels", in which it is stated that "in a given steel the increase in hardenability is roughly parallel to, but does not correlate well with, the percentage of boron as determined by chemical analysis of the steel".

‡Definite relationships between hardness (and the other room temperature tensile properties) and notched-bar Charpy impact at −40° F. to establish satisfactory toughness are given by Herres and Jones in *Metal Progress* last month, p. 462.

steel industry is that of the increasing content of residual alloys derived from circulating scrap. The amounts of these residuals vary widely from one mill to another, with the result that some of the more simple steels vary widely in properties according to the mill at which they are produced. For example, let us consider a "plain carbon" forging steel specified to contain 0.35 to 0.42% carbon and 0.60 to 0.80% manganese. As produced at one mill it may contain less than 0.03% nickel, less than 0.03% chromium and less than 0.01% molybdenum. Steel ordered to the same chemical specification from another mill might contain 0.20% nickel, 0.12% chromium and 0.05% molybdenum. The properties would obviously be different. (If an additional element is specified at a value above the highest usual residual — such as, say, 0.15 to 0.25 Mo — then one variable is removed; this becomes, of course, a different type of steel.)

It will be noted that the prewar trend in the development of customers' specifications has been in the direction of chemical ranges or limits even closer than those previously recognized as standard. The intention was to provide adequate control of hardenability through control of chemical composition alone, so that hardenability testing would not even be necessary. It may be necessary to reverse this trend and greatly widen the chemical ranges specified for the alloy elements and to permit adjustments within these widened ranges to meet desired ranges of hardenability.* This would be more feasible now than formerly, because of the more quantitative information now available regarding the specific contributions of the various elements to hardenability. Some such scheme might provide a framework in which boron could be used effectively.

Summary

1. Boron can readily be introduced by adding in the ingot molds or, preferably, the ladle *(a)* ferroboron, *(b)* one of a number of complex ferroalloys containing boron together with one or more strong deoxidizers, or *(c)* borax mixed with a reducing agent. The use of a ferroalloy is more common than the use of borax.

2. The hardenability of steel is markedly increased by the addition of boron. The amount that must be added to produce the maximum increase in hardenability is usually from 0.001 to 0.005% of the weight of the steel.

3. Plenty of boron is available in the United States in the form of borax and other borates.

4. There is no generally available method for the determination in steel of the small amounts of boron under consideration, although results of some accuracy seem to have been obtained in a few laboratories by spectroscopic methods. [This statement was correct in 1942.]

5. There is not sufficient evidence to state whether boron is recovered from boron-treated steel scrap on remelting. Some boron is recovered on remelting boron-treated cast iron scrap in a cupola. Indications are that no appreciable amount of boron is recovered in making steels containing less than 0.50% carbon by the basic openhearth process, but that appreciable recovery might occur in making high carbon steels, or in acid melting processes or in electric arc furnace melting.

6. Because of the difficulty of analysis, the amounts of boron actually present in boron-treated steels are not exactly known. Indications are that recovery is quite high when additions are made to well deoxidized steel.

7. The amount of boron that must be added to produce maximum hardenability is less the more strongly the steel is deoxidized.

8. The effect of boron added in the ladle tends to fade out or diminish toward the end (last ingot) of the heat, but it is believed that this difficulty can be satisfactorily overcome.

9. Mold additions are apt to result in lack of uniformity, dirty steel and poor surface, and are undesirable except for experimental purposes.

10. Addition of too much boron to steel results first in moderately low ductility and toughness, then in real brittleness, and finally in complete hot shortness.

11. In plain carbon steels containing 0.40 to 0.60% carbon and 0.70 to 1.00% manganese, the hardenability increase obtainable from boron is equivalent to that obtainable from about 0.20 to 0.45% additional manganese. The corresponding savings in added manganese amount to about 5.3 and 12.0 lb. of Mn per ton of ingots, respectively. Potential savings of other strategic alloys, such as chromium and molybdenum, can be judged approximately from known relationships.

12. Most laboratories are not at present able to determine the amount of boron in steel, and even though an accurate determination were made, the boron content without supplementary information probably would not suffice to assure that the desired results had been obtained. There is, therefore, a somewhat unusual problem in setting up specifications and tests for acceptance of boron-treated steels. For the present it appears that reliance would have to be on physical tests, especially for hardenability and toughness.

*This seems to be the trend with the recent "H" steels, where the hardenability is specified along with a somewhat liberalized range in chemistry — EDITOR.

By Walter E. Jominy
Staff Engineer
Chrysler Corp., Detroit

Development in Aircraft Engine Metallurgy, 1920-46

WHEN one observes the differences between a modern radial air-cooled (or in-line liquid-cooled) engine and the old Liberty engine, he is conscious of a tremendous development.

Mechanical engineers who specialize in aircraft engines would be quick to admit that this improvement in their field would not have been possible without the metallurgical developments since World War I. Not many people, however, seem to realize that the basic improvements in metallurgical processes or materials make possible the really great forward steps in mechanical engineering. It is intended in this, the Detroit Chapter's third annual William Park Woodside lecture, to discuss briefly some of these basic improvements. Some of them, such as sintered carbides, induction heating, and chromium plate, are so well known that it seems rather startling to realize that they were not available in the last war. Other developments, such as the S-curve of Bain and Aborn, and hardenability conceptions, affect aircraft engine materials only in a general way.

If we scan the materials in aircraft engines of World War I and compare them with those used in World War II we find many newcomers. These are magnesium, sodium, silver, lead plate, indium plate, beryllium, stainless steel, columbium, titanium, selenium, chromium plate, sintered bushings, sintered carbides, molybdenum high speed steel, nitralloy, forged aluminum, heat treated aluminum castings, and high temperature alloys.

Important new processes or tests developed in the interval of peace are nitriding, grain size control, S-curves, hardenability testing, induction hardening, magnaflux testing, furnace atmosphere control, hydrogen brazing, Rockwell hardness testing, shot blasting, and quantitative spectrography. Let us describe a few of these as fully as time will permit.

Magnesium

Of the many recent metallurgical developments, magnesium has attracted much attention. It is used in the form of strip, sheet, bars, forgings, and castings, but seldom without other metals being added in relatively small percentages to improve the properties and usability of the alloy. With specific gravity of about 1.80, magnesium is the lightest structural metal commercially used, and has helped engineers greatly in reducing the weight-power ratio of aircraft engines.

Although there are certain necessary precautions in making magnesium castings, such as prevention of fire by suitable fluxes during melting and casting, and by careful control of the solution treatment temperature and by the addition of sulphur dioxide to the furnace atmosphere, magnesium has proved itself a commercial material. Its cost is low enough for aircraft applications. One of the important items of cost is the large number and size of risers, gates, and sprues necessary to insure castings of aircraft quality — commonly three times the casting weight. Rapid strides were being made toward the end of the war in learning how to reduce this surplus weight of metal.

An item of importance in considering cost is the easy machinability of magnesium castings. Where a large amount of machining with good finish is required, the cost of the finished magnesium part may compare favorably with aluminum. Physical properties of magnesium and common aluminum sand castings compare satisfactorily with the common aluminum sand castings.

The question often asked by the designer of today is, "What are the requirements which call for aluminum and what are those which call for magnesium?" If costs are considered secondary to performance, as in aircraft engines, magnesium castings properly protected against corrosion will be used. There may be a few instances where such special properties as thermal conductivity, electrical resistivity, coefficient of expansion, radio interference, resistance to scoring, resistance to wear, and modulus of elasticity may call for the one metal rather than the other. For peacetime activities, magnesium should have a field where the additional lightness compensates for additional costs, as in castings for vacuum cleaners, outboard motors, and similar portable items.

Silver

Aside from an extensive use of silver brazes, to be mentioned under another heading, the important application of silver in aircraft engines is in the main bearings.

One of the chief difficulties experienced with the old Liberty engine was with connecting rods and main bearings. Bearings were made of tin-base babbitt on bronze backs; they caused many engine rejections by failure to last 50 hr. in the test stand. The use of silver plating on steel backs has permitted much higher load concentrations and speeds. Whereas 1200 psi. is considered the limiting safe load for babbitt at speeds used in automotive applications, 5000 psi. (even 6000 psi., temporarily) can be used on silver, plated with lead and indium.

Silver has a much higher strength at moderately high temperatures than babbitt and, of course, has excellent heat conductivity. Its corrosion resistance is excellent. It also has good wear resistance. In order to improve the scoring resistance, which is of importance in the run-in period, it is aircraft policy to plate somewhere between 0.0002 and 0.0006 in. of lead on the silver; following this, to make the lead resistant to corrosion, a small quantity of indium is plated on the lead (about 4% of the quantity of lead). The indium is then diffused into the lead by heating in oil at 450° F. Thickness of silver plate in the finished bearing is usually in the neighborhood of 0.005 to 0.010 in.; for some applications it is as high as 0.016 to 0.024 in.

When silver is plated on steel for bearing purposes a flash of copper or nickel is first plated on the steel backing. If a copper flash is used, the subsequent silver plate is annealed at about 450° F.; if nickel is flashed on the steel the part is annealed at 950° F. in a nonoxidizing atmosphere or in fused salt. Unless a good bond has been obtained, the silver will blister. The most severe test for blisters can be obtained by heating after finish machining — if distortion can be avoided.

(Perhaps it would be well to mention that an important advance in the art of making bearings was through the use of a steel backing material in the place of bronze, which was used in the last war. Because of its high modulus of elasticity, steel permitted less movement of the babbitt, and consequently lower stress and fewer fatigue failures. Since common failures of bearings are from fatigue of the soft bearing material, steel backing has greatly increased the life of the bearing.)

Stainless Steel

Stainless steel is used in the modern aircraft engine in many applications such as screens, fuel lines, injection fuel adapters, fittings, lockwire, and miscellaneous tubing which cannot be conveniently rustproofed on the inside.

The most common variety is the austenitic 18-8 (chromium-nickel) steel. If the parts made from it were to be heated to 1000° F. or above, "stabilized" stainless was used rather than the standard alloy. Stabilizing alloy was either columbium or titanium.

One of the common uses for stabilized stainless was for parts to be silver brazed. (A silver brazing alloy commonly used contained about 50% silver, 15% copper, 16% zinc, and 18% cadmium.) This made a satisfactory joint, stainless steel to stainless steel. Thousands of feet of tubing were also brazed to fixtures with good success.

Since it appeared to be more difficult to make clean tubing (with seams) of columbium-stabilized alloy, this greater difficulty plus the additional cost of columbium increased the price of small tubing to about 25% higher than if it were made of plain 18-8 material.

The metal selenium was also used in stainless steel to increase its machinability. The amount added ranged from 0.10 to 0.35%; frequently the phosphorus was also increased to about 0.10 to 0.17% for the same purpose. Wherever these free-machining types can be tolerated there is no question but that a very great advantage is obtained in their machinability.

Chromium Plate

Chromium plating is perhaps too common to discuss as a *new* development. One of the applications in aircraft engines is in holes in which inserted pins oscillate or move slightly. Plating reduces wear and also eliminates frettage.

"Porous" chromium plating also has been used in the top piston ring — porous, so it will be wetted by a scant supply of oil. Definite increase in the life of piston rings has been demonstrated with the porous type of chromium plate. About 0.005 in. thickness is common practice.

Sintered Bushings

Sintered bushings, commonly called "Oilite", made from powdered copper-tin, are quite well known today by automotive engineers. It was found possible to replace many cast copper-lead bushings with sintered copper-tin in aircraft engines.

The cast bushings contained lead in the neighborhood of 25% and tin about 5%. While they have good bearing properties they became rather difficult to purchase because so few vendors were capable of meeting our specifications. When attempts were made to make them in large quantities, it appeared that the segregation of the lead became a major problem. Just how large the lead particles could be in any given bushing was not known and we were more or less forced to rely on the generality that the lead "should be well dispersed". There was a good deal of pressure to find substitutes and in many applications it was found that the sintered copper-base bushing performed equally well. The latter has the advantage that it can often be pressed into the size desired, and requires very little machining.

It is a good precaution to avoid grinding a sintered copper bushing, to eliminate any emery getting into the pores of the bushing.

Forged Aluminum

Forged aluminum has come to be a useful material during World War II. By proper heat treating tensile properties of 65,000 psi., elongation of 10%, and hardness of about 140 Brinell (1000-kg. load) could be obtained.

One of the common uses for aluminum forgings was the piston. It had a combination of lightness, strength, resistance to scoring and wear, impossible to obtain in any other material. This piston alloy (which contained about 2% Cu, 2% Ni, and 0.70% Mg) was forged at about 850° F. Its heat treatment was: Solution treat at approximately 950° F. for 6 hr., quench in boiling water, and age at around 340° F. for from 8 to 10 hr., according to requirements. After rough machining the pistons were aged 5 hr. at 450° F.

Nitralloy

Use of nitralloy steel is quite common in aircraft engines when high hardness is required on the surface and, in addition, distortion of the part during heat treatment would prevent it from being carburized and hardened. One of the commonest applications is in gears of intricate design.

The usual composition is the "135 modified", which contains 0.95 to 1.35% aluminum, 1.40 to 1.80% chromium, 0.30 to 0.45% molybdenum, and 0.38 to 0.45% carbon. (A small amount of "nitralloy-N" was also used, which contained 3.50% Ni, about 1.10% Cr, 1.25% Al, 0.25% Mo and 0.25% C, and which age hardens at the nitriding temperature to about 400 Brinell.)

One of the difficulties encountered with nitralloy steel is the "white layer", which must be removed if high surface loads are to be endured. To remove this white layer it is a common requirement to grind from 0.001 to 0.003 in. after nitriding. Many shops found this requirement difficult; there was a tendency either to lap the part and take off merely 0.0001 in. or else to grind off too much. As is well known, the desirable high hardness of nitralloy steel is relatively shallow, so that grinding 0.008 to 0.010 in. will frequently reduce the hardness to the point where wear resistance is poor. Unless very carefully designed fixtures and accurate locating points are used, it is quite easy to grind too deeply, and much scrap and many poor quality parts have been produced from this cause.

Failure to remove the white layer is often responsible for flaking or spalling during engine performance. Anyone using nitralloy steel should be warned of this condition, since parts may be ruined during grinding, although metallurgically the steel and heat treatment are highly satisfactory. The nitriding process, in fact, seems to be almost trouble-free. A relatively wide range of dissociation of ammonia will give highly satisfactory results; case depths are very uniform and easily duplicated. One precaution is necessary: Before any parts are nitrided the furnace must be

saturated so the fixtures do not take up nitrogen and thus rob this gas from the parts being treated.

Nitriding is also applied to steels other than those developed for nitriding. It has been used with good success to stop scoring on parts made of S.A.E. 1137 steel. In this practice, 5 hr. at 970° F. gives a very definite skin hardness.

S.A.E. 4300 steels have also been nitrided to increase resistance to fatigue. The nitrided hardness is in the neighborhood of 550 to 600 Vickers and an increase of fatigue strength of about 25% can be obtained by this means.

Another steel which is nitrided in production is a high molybdenum steel used in crankshafts in some of the in-line engines. This steel contains 0.30 to 0.35% carbon, 0.70 to 0.90% manganese, 0.50 to 0.80% nickel, 0.90 to 1.20% chromium and 0.90 to 1.10% molybdenum.

New Processes

So far as the new processes which have been developed since the last war are concerned, they are so well known that it seems unnecessary to discuss them here except to give their latest developments as applied in aircraft engine metallurgy.

Grain Size Control — It is common aircraft practice to call for fine-grained steel, but to accept a few grains as large as No. 3.

The question often arises as to why we should be concerned with the grain size of medium carbon, oil hardened steel which is not heated beyond 1500° F. in the hardening process. One answer to this is that a large grain size might affect the normalizing cycle. Furthermore, fine grain does indicate a somewhat different treatment of the steel at the mills. Whether the effects of such a treatment are deleterious has never been demonstrated, so far as I know, but there is a strong feeling in favor of fine-grained steel among metallurgists.

Hardenability Testing — At least 14 of the most recent A.M.S. aircraft specifications, as developed by the S.A.E., now include hardenability as measured with the end-cooled bar. An example of the application of hardenability testing may be quoted in connection with the crankcases made at Dodge-Chicago plant. A.M.S. 6382 (which is S.A.E. 4140 steel) was specified for the crankcase forging, weighing about 300 lb. Before too many heats of this steel were forged we found one which would not harden properly when quenched in oil. Hardenability bars were cut from these crankcases and were C-50 hard only for a distance of 5/16 in. Hardenability bars were then made from some of the heats which hardened properly, and they hardened to C-50 for 10/16 in. As a result we promptly changed our specification to require a minimum of Rockwell C-50 at 12/16 in. on the end-cooled bar. It was necessary to permit the steel producers to run over the specification limitations in manganese, chromium, and molybdenum in order to guarantee this hardenability. Heats received thereafter averaged well to the top side of the specification, but no further trouble was encountered in hardening crankcases as long as a minimum of C-50 at ¾ in. was maintained.

It might be worth noting that somewhat lower hardenability readings were obtained when bars were machined from the 9-in. steel billets (as was convenient in our laboratory) rather than when they were first forged to 1¼-in. round, in accordance with the S.A.E. specification for hardenability. Our test bar was cut with axis half way between the center and surface of the 9-in. square billets, and from billets which were rolled from the bottom of the ingot (since the bottom of the ingot generally has the lowest hardenability). The steel producers made their test bars by forging, and we seemed to get as low as 9/16 in. on steel heats for which they reported the deeper hardenability of 12/16 in. This difference is worth noting for those who expect to purchase steel on hardenability specifications.

Magnaflux testing was very extensively used during World War II. Thousands of parts have been scrapped because of magnaflux indications, and much time has been spent in attempting to determine whether certain indications could be tolerated and what indications warranted scrapping the piece.

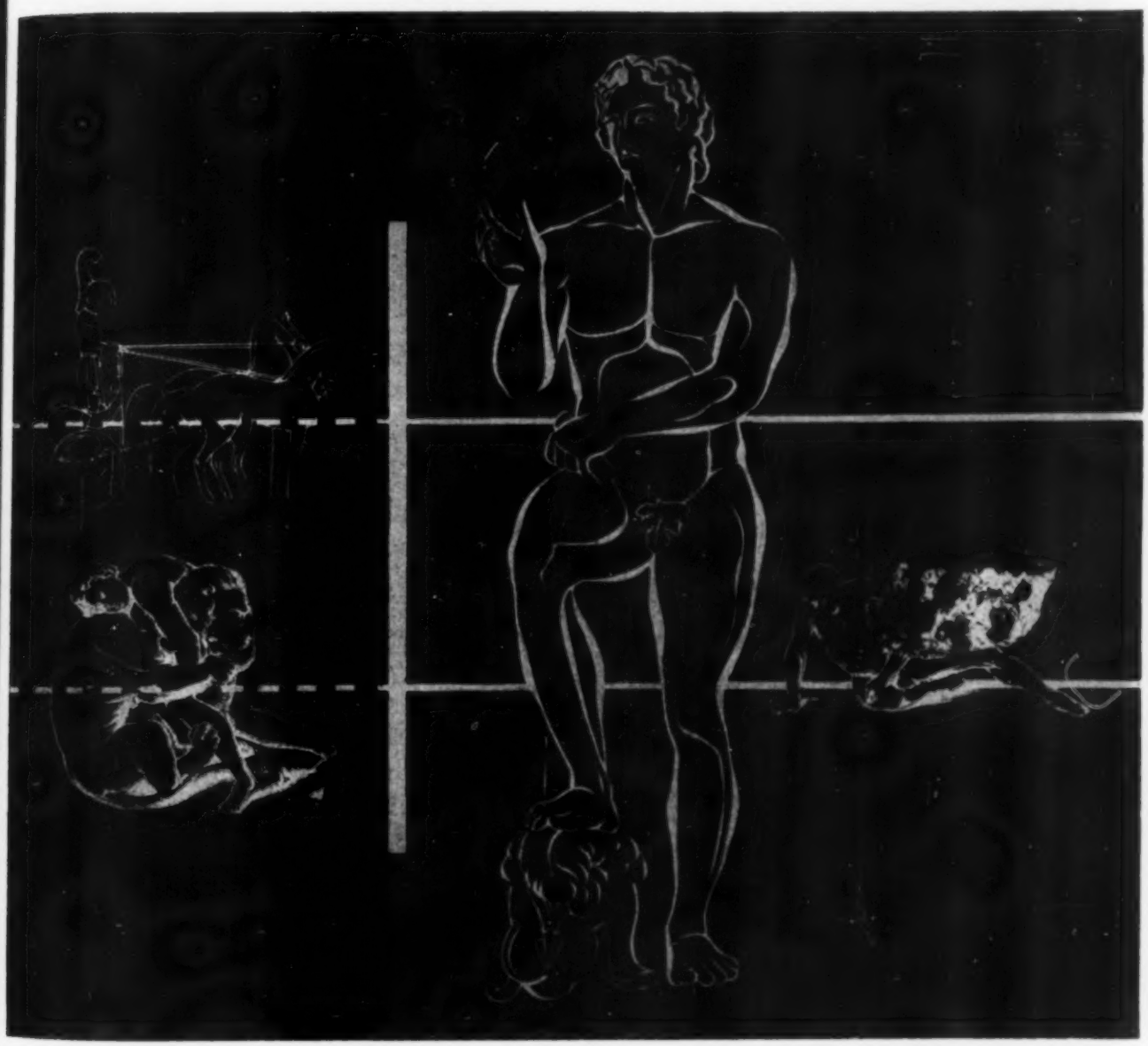
In general, indications in sharp corners, fillets, at the base of threads, and any indications that are transverse to the grain flow were usually looked upon as unsatisfactory. Indications of flaws which did not come to the surface were practically always acceptable unless they occurred in sharp corners or fillets. If the indications come to the surface the guiding consideration is their severity or the apparent size of the inclusion. Any kind of a crack, even though it was a grinding crack, has commonly been the cause of rejection in aircraft parts. It has been found, however, that thousands of parts have magnaflux indications which do not affect their usability. It has been a rather common practice to run parts with questionable indications in model test engines, and observe whether there is any tendency for failure under test conditions.

A difficulty which was occasionally experienced was through the erroneous requirement of magnaflux on high sulphur, free-machining steel. Obviously such steel always has bad magnaflux indications.

IT TAKES MORE THAN MUSCLE

According to legend, Polydamas, the Greek athlete, killed a lion with his bare hands, stopped a chariot in full flight, and lifted a raging bull off the ground with ease. His career, however, came to a spectacular end when he tried to catch a huge falling rock.

Today, sudden, heavy loads end the life of many steel parts. Low temperatures, for instance, can have a depressing effect on the impact strength of steels. Molybdenum steels, which combine deep hardening and freedom from temper brittleness, reduce this risk.



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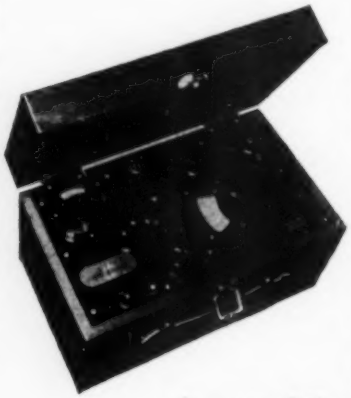

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Personals

HARRY W. MCQUAID has resigned from Republic Steel Corp., where he was manager of the process and product development division, to establish consultant services in Cleveland.

QUENTIN D. MEHRKAM, formerly employed as production metallurgist by Thompson Products, Inc., Cleveland, has recently joined the metallurgical staff of the Ajax Electric Co., Inc., Philadelphia.

American Foundrymen's Assoc. announces the retirement of CHARLES EDGAR HOYT, who has held the offices of secretary, convention and exhibits manager, executive vice-president and treasurer. Also announced is the election of WILLIAM W. MALONEY as secretary-treasurer. Appointed as technical director is S. C. MASSARI, and JOHN P. MULLEN is named assistant treasurer.

Announcement has been made that J. G. RIPSTRA will be representative in the Detroit area of the Banox division of Calgon, Inc., Pittsburgh, and RICHARD J. SKILLMAN will operate from the Philadelphia office.

W. F. PRAVEL has been transferred to Chicago as district manager of toolsteel sales for Allegheny Ludlum Steel Corp.

H. L. EDSALL, advertising manager for Radio Corp. of America and member of the *Metal Progress* Advisory Committee, has announced his resignation in order to devote his time to writing. His first book, "Borrow and Prosper", has just been published.

THEODORE A. COHEN has announced the formation of his own company, the Taco Engineering Co., Chicago, a consulting, designing and manufacturing organization specializing in industrial process control.

EARL S. PATCH and C. ROBERT TALMAGE announce the formation of a consultant service in powder metallurgy at Stamford, Conn.

Appointment has been made at the University of Notre Dame of ETTORE A. PERETTI as associate professor of metallurgy. Mr. Peretti was formerly assistant professor of metallurgy at Columbia University, New York.

E. E. MUELLER has joined C. U. Scott & Son, Inc., Rock Island, Ill., as metallurgist. He has had 30 years' experience in the steel industry serving as metallurgist and sales specialist.

Pennsylvania State College announces the appointment of WILLIAM J. REAGAN as associate professor of metallurgy.

CHARLES S. BARRETT has resigned as professor of metallurgical engineering at Carnegie Institute of Technology to join the research staff of the Institute for the Study of Metals at the University of Chicago.

JOHN R. DAESEN has been named president of Iron, Inc., a new division set up by Continental Machines, Inc., to operate the high-purity iron powder plant now under construction on the Mesaba iron range of northern Minnesota.

JANET Z. BRIGGS has joined the metallurgical staff of the Climax Molybdenum Co., New York. Previously she was metallurgist for the Crucible Steel Co. of America.

JOSEPH E. WORKMAN, formerly Chicago district manager, has been appointed assistant sales manager for Latrobe Electric Steel Co. ROBERT F. FRAZURE, formerly Toledo manager, becomes Chicago district manager, and RALPH H. BAILEY will move from Dayton to Toledo to be district manager.

Announcement has been made by the Alloy Cast Steel Co. of the appointment of C. H. WELCH, formerly superintendent, as plant manager. He succeeds W. A. DORSEY, who recently retired as vice-president and works manager. J. E. GICKLER will become superintendent.

WILLIAM A. THIEL has been promoted from master mechanic to manager of the Gary plant, American Bridge Co.

EDWIN K. PRYOR, has been made west coast representative of Chas. Taylor Sons Co. He recently completed a year's special work on the staff of Battelle Memorial Institute, Columbus, Ohio.

J. E. ARTHUR, superintendent of melting, Crucible Steel Co. of America, has been elected president of the Electric Metal Makers Guild. R. H. FRANK of Bonney Floyd Co. is vice-president, and D. L. CLARK, superintendent of melting of Simonds Saw and Steel Co., is secretary-treasurer.

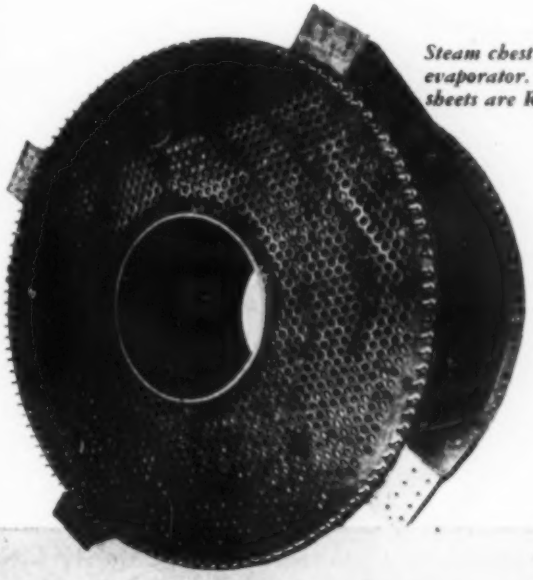
Skilful designers take advantage of REVERE'S many metals

THIS large evaporator equipment affords an excellent example of skilful designing to take advantage of the special characteristics of two of the Revere Metals. For high heat conductivity and corrosion resistance, Revere copper tube and tube sheets were used for the steam chest. For the strength of mild steel and the corrosion resistance of copper, Herculoy plates were used.

There are many different Revere Metals, because no one metal can possibly serve all purposes. The important thing is to select among these metals those most suitable for each given set of conditions. Sometimes this is not easy, requiring a skilful balancing of such factors as corrosion resistance, strength, weight, cost per pound, cost per cubic foot, cost of fabrication, time consumed in fabrication, service expectancy, and even appearance. We will gladly discuss with you the many, varied, and sometimes contrasted virtues of Revere Metals, either in general terms, or in relation to a specific product or piece of equipment.

Revere Mill Products include—*Copper and Copper Alloys:* Sheet and Plate, Roll and Strip, Rod and Bar, Tube and Pipe, Extruded Shapes, Forgings; *Aluminum Alloys:* Tube, Extruded Shapes, Forgings; *Magnesium Alloys:* Sheet and Plate, Rod and Bar, Tube, Extruded Shapes, Forgings; *Steel:* Electric Welded Steel Tube.

Catchall, 90" x 5' 5" face to face, made of Herculoy.



Steam chest of 11' ID x 30' 6" evaporator. Tubes and tube sheets are Revere Copper.

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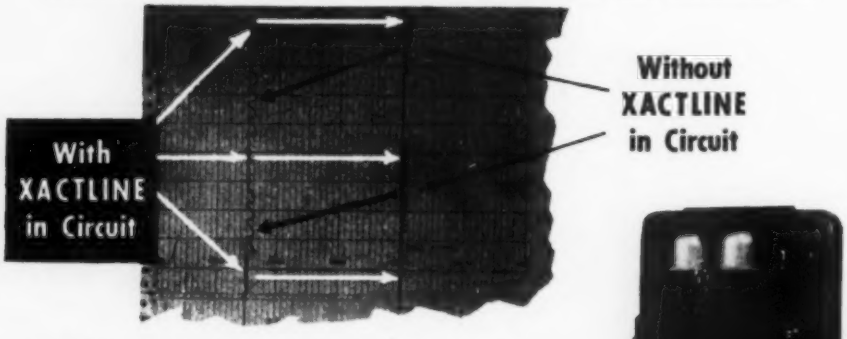

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Personals

A. W. SCHLECHTEN, recently on leave from Oregon State College as a metallurgist at the Northwest Electrodevelopment Laboratory of the U. S. Bureau of Mines, Albany, Ore., has now been appointed professor of metallurgy at Missouri School of Mines and Metallurgy at Rolla, succeeding PROF. H. R. HANLEY, who has been appointed professor emeritus at the school after 23 years of service.

CHARLES G. PURNELL, formerly district contact metallurgist for Carnegie-Illinois Steel Corp., is now associated with Cabot and Co., Inc., Pittsburgh advertising agency.

LESTER A. LANNING, formerly assistant manager of the Bristol plant of New Departure Division of General Motors Corp., has been appointed manager of the new Sandusky plant of New Departure.

Upon release from active duty with the rank of lieutenant commander in the U. S. Navy Reserve, WILLIAM Y. WEBB has been employed by the Materials Division, Navy Department, Washington, D. C., as an industrial engineer in nonferrous minerals.

STEWART M. DEPOY has resigned from Delco Products Division, General Motors Corp., as chief metallurgist and has become affiliated with the Dayton Forging and Heat Treating Co. as superintendent.

ERIC R. JETTE has resigned as professor of metallurgy in the School of Mines, Columbia University, and is now head of the chemistry and metallurgy division at the Los Alamos Scientific Laboratories of the Manhattan District, Santa Fe, N. M.

J. DONALD ZAISER was elected president and general manager of Ampco Metal, Inc., Milwaukee, to succeed his father, C. J. ZAISER, who died July 29.

E. R. MERTZ has been appointed associate professor in general engineering at the University of Southern California.

CARL O. SUNDBERG, now released from active duty in the U. S. Navy, has been appointed process metallurgist with the Diamond Chain & Mfg. Co. of Indianapolis, Ind.

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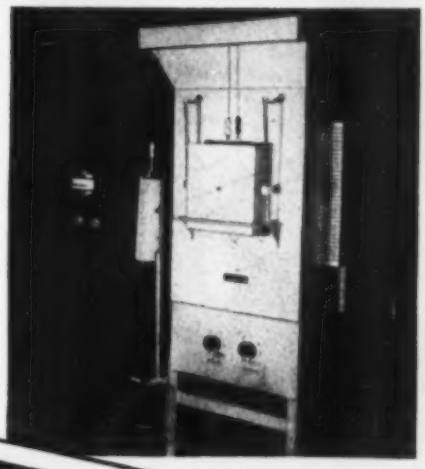

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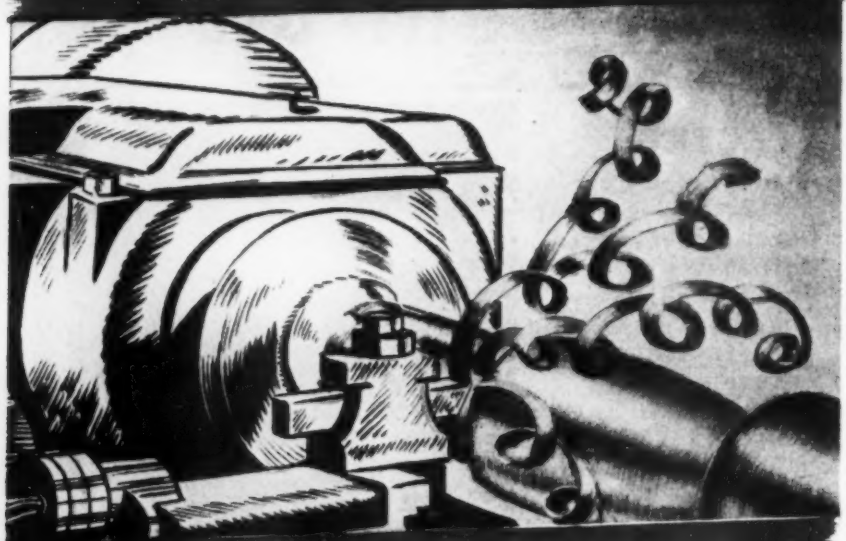

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Stress-Strain Curves for Magnesium*

THE FUNDAMENTAL relation of stress to strain is required by the designer for many problems. Typical stress-strain curves up to the yield strength in tension and compression are presented for Dowmetal FS-1h sheet (longitudinal and transverse), J-1h sheet (longitudinal and transverse) and O-1 HTA extrusions. For these alloys distribution curves based on a large number of tests are given for compressive proportional limit, compressive yield strength, compressive modulus of elasticity, tensile proportional limit, tensile yield strength, tensile strength, tensile elongation and tensile modulus of elasticity. Individual curves from a few tests on typical material are presented on other commercial alloys in the form of forgings, die castings, extrusions and sheet.

The accurate determination of a stress-strain curve calls for observance of careful experimental technique. The modulus of elasticity is particularly sensitive to various factors in the testing. Errors found in normal testing account for the variation in the modulus obtained and are not due to inherent differences in the material. On alloys with a low proportional limit, the testing technique must be good or even the yield strength will be in error.

With careful testing, the modulus of elasticity has been found to be substantially constant in compression and tension. The values were distributed quite closely around a mean of about 6,500,000 psi. which should be used in normal design calculations.

The ratio of compressive yield strength to tensile yield strength averages slightly more than unity for castings. In certain wrought alloys, the ratio may be as low as 0.4 to 0.6, especially for the low strength extrusion alloys. High strength sheet and extrusions have ratios from 0.8 to unity. Low ratios are considered to be due to the combined action of the preferential grain orientation and the lower yield strength in *(Cont. on p. 700)*

*Abstracted from "The Relation of Stress to Strain in Magnesium-Base Alloys", by E. J. Eastman, J. C. McDonald and A. A. Moore, *Journal of the Aeronautical Sciences,* V. 12, July 1945, p. 273 to 280.

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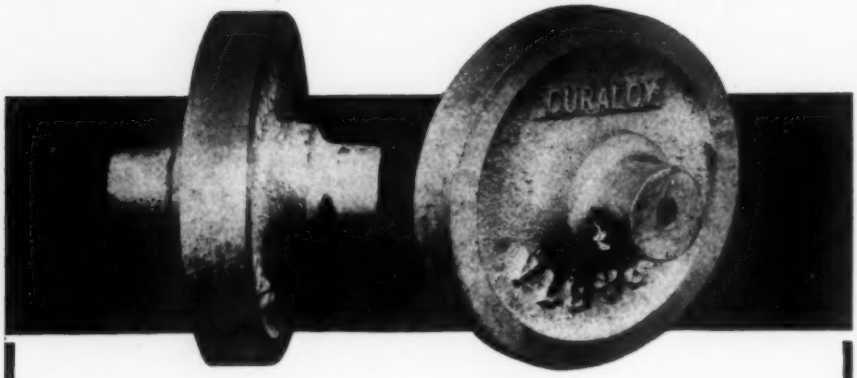

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Stress-Strain Curves for Mg

(Cont. from p. 698) compression of the grains under these conditions. The ratio of the proportional limit in compression to that in tension behaves somewhat similarly to the ratio of the yield strengths.

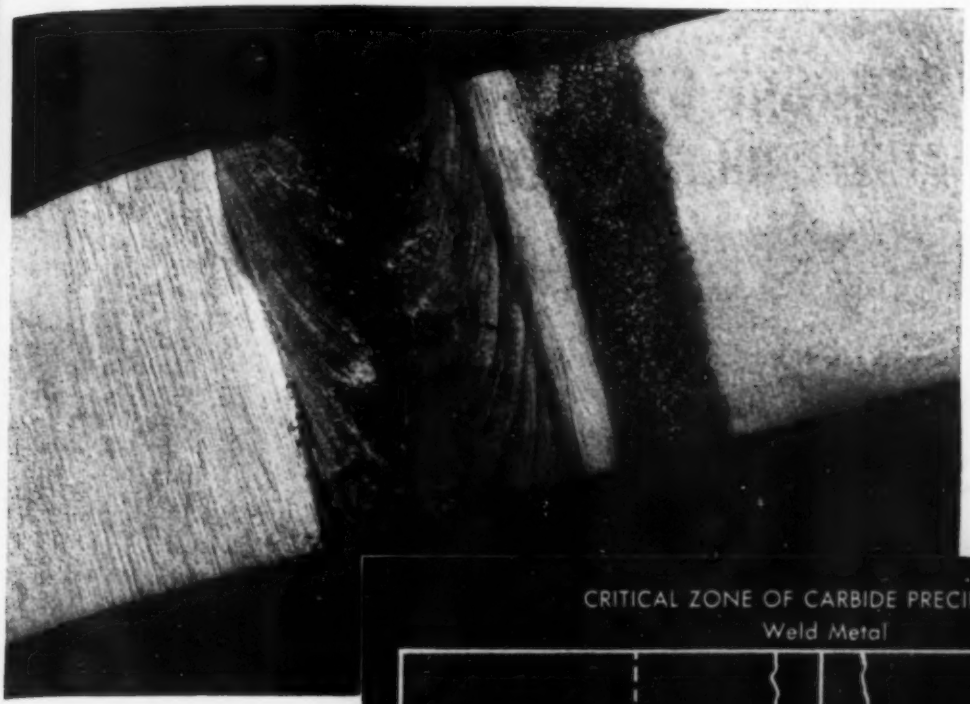
In actual shape, the stress-strain curves of cast alloys are similar in both tension and compression. In wrought metal, the compression curves tend to break away from the modulus line faster than those in tension, so it is often feasible to determine the yield strength in compression by the drop of the beam.

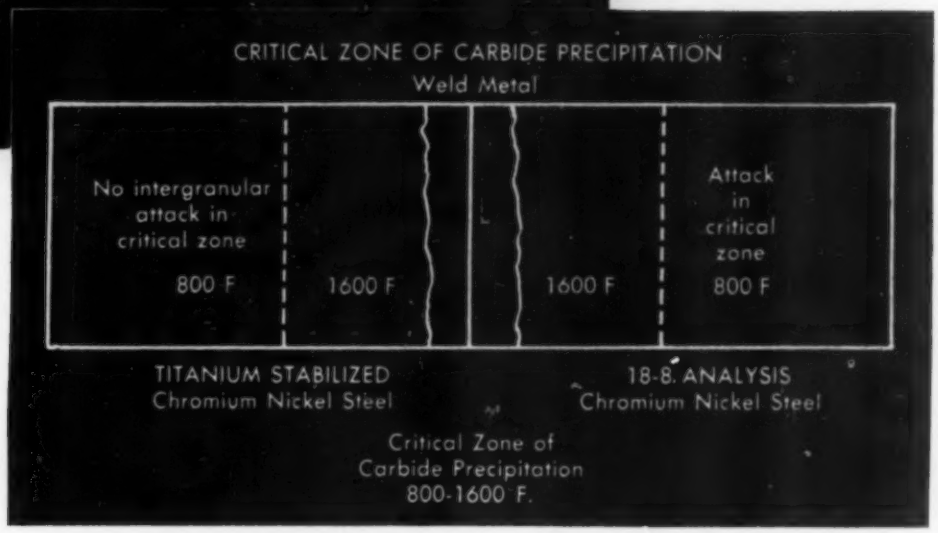
Vibration in Machining*

VIBRATION of lathe tools was studied as an introduction to the general problem of vibration in machining operations. In the present tests, the amplitude and wave form of the tool vibrations were recorded on a cathode ray oscillograph by means of a specially developed pick-up. The vertical cutting force was measured by an electromagnetic dynamometer. The contour of the machined metal was examined with a profilograph. The main factors affecting vibration were tool sharpness, cutting speed, tool overhang and feed.

In the first series of tests, the feed per revolution was greater than the length of contact of the tool. A carbide-tipped tool was used to cut a low carbon steel with hardness of Vickers 156 to 180. Two distinct phases were evident in considering the effect of cutting time and tool wear on the vibration. In the first, the vibration was small, somewhat irregular and increased slowly, while the wear of the tool edge continued steadily. In the second, a large, steady vibration persisted at almost constant amplitude as the rate of wear began to increase after a temporary pause. The transition period was almost instantaneous in most cases. The limiting amplitude *(Cont. on p. 702)*

*Abstracted from "The Mechanism of Tool Vibration in the Cutting of Steel", by R. N. Arnold. (Report of Subcommittee on Carbide Tools, Institution of Mechanical Engineers.) *The Engineer*, Nov. 2, 1945, p. 355 to 356; Nov. 9, 1945, p. 379 to 380.





HOW

Titanium Prevents Intergranular Corrosion in Welding Stainless

In the welding of austenitic stainless steels, the retention of carbides in solution is not possible because the resulting heating between 800 and 1600°F. precipitates the carbon present as chromium carbides in an intergranular pattern. In this condition the zones near the welds are predisposed to intergranular corrosion in certain media.

Titanium, the stabilizing element, prevents precipitation of chromium carbide in an intergranular pattern by virtue of the fact that it has greater affinity for carbon than any other element has for carbon, and accordingly, the carbides of titanium are uniformly dispersed thereby preventing intergranular precipitation and corresponding intergranular corrosion.

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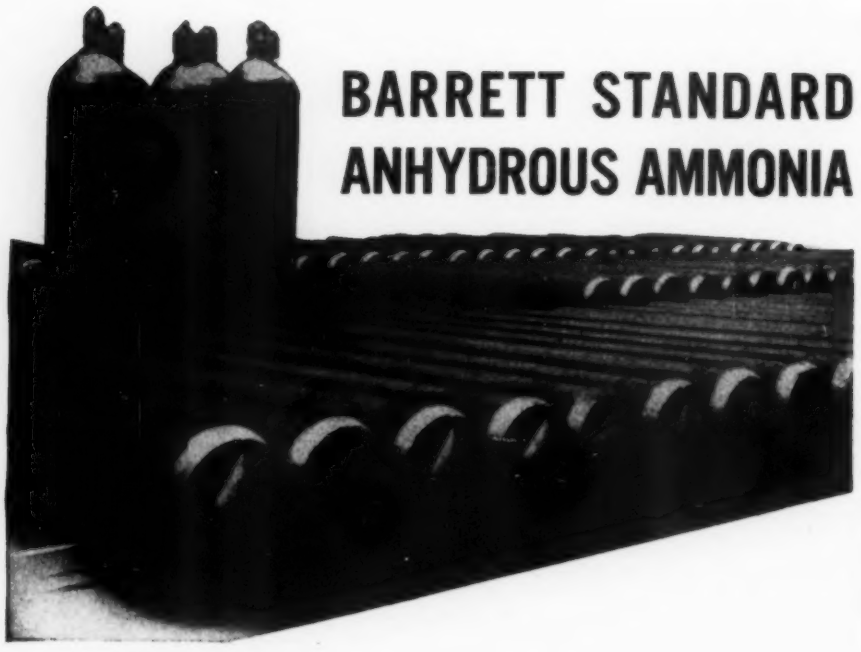

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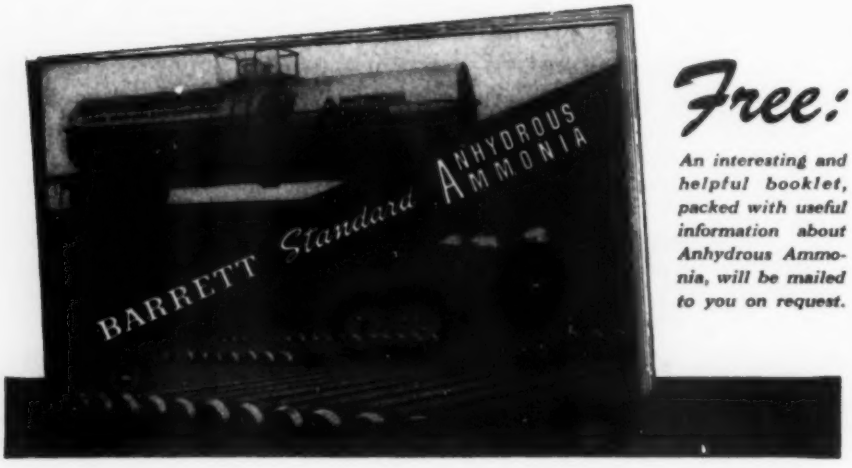

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Vibration in Machining

(Cont. from p. 700) was attained more quickly when the cutting speed was increased.

The practical significance of these results may be judged from the fact that 0.02 in. wear is generally allowed on carbide tools before regrinding, but in these tests, with a cutting speed of 550 ft. per min., the maximum severity of vibration was reached after a wear of only 0.04 in. The profiles of the machined surfaces showed a lack of symmetry with a steep entry followed by a more gradual exit of the tool. A sharp tool with an adequate front clearance when vibrating cut a smooth profile of somewhat sawtooth appearance. As the tool point wore, the action became more complicated and the flat worn at the tool point modified the shape of the profile. The surface contour was greatly influenced by speed. Eventually, when the ratio of wear to the surface wave length became unity, the wave form cut by the leading edge was almost obliterated by the trailing edge. For moderate vibration amplitudes, the tool vibration wave form closely approached a sine wave but when the wear on the tool point was well advanced, the wave forms were complex, showing the existence of higher harmonics.

There are at least four distinct effects introduced by initiating vibration. The vertical force on the tool may vary as a result of *(a)* the variable depth of cut produced by the movement of the tool point, *(b)* the variable top rake resulting from the change of slope, *(c)* the variable speed of the tool relative to the work, and *(d)* the influence of the cutting action of the flat on the tool point. The influence of the first two is small and may be neglected; the last two are of paramount importance. While the third may be measured, no corresponding measurement has been found possible for the fourth. The effect of speed variation during each cycle depends on the material being cut and to a lesser extent on the shape of the tool. A negative characteristic in the force speed relation introduces dynamical instability which results in vibration. A positive characteristic results in dynamical stability. The damping characteristics of the tool shank may be a determining influence as to whether *(Cont. on p. 704)*

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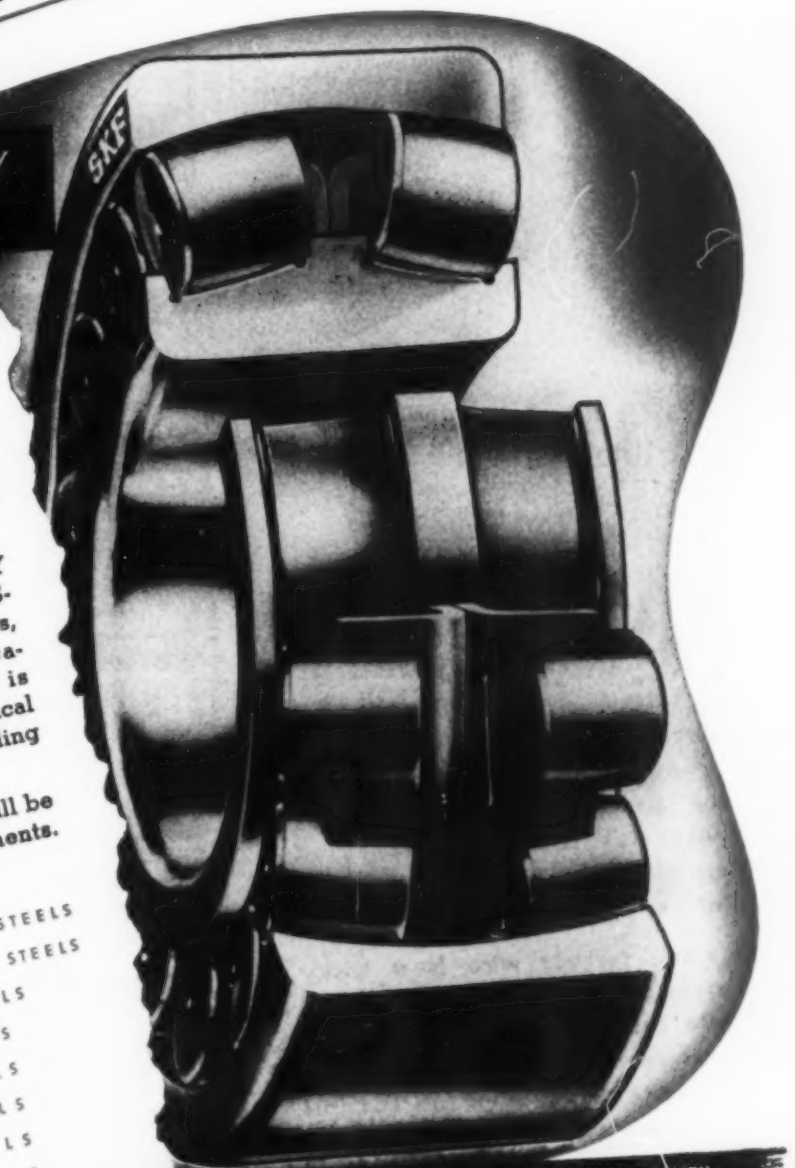

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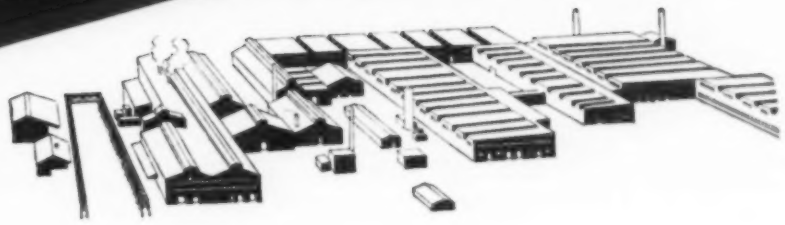

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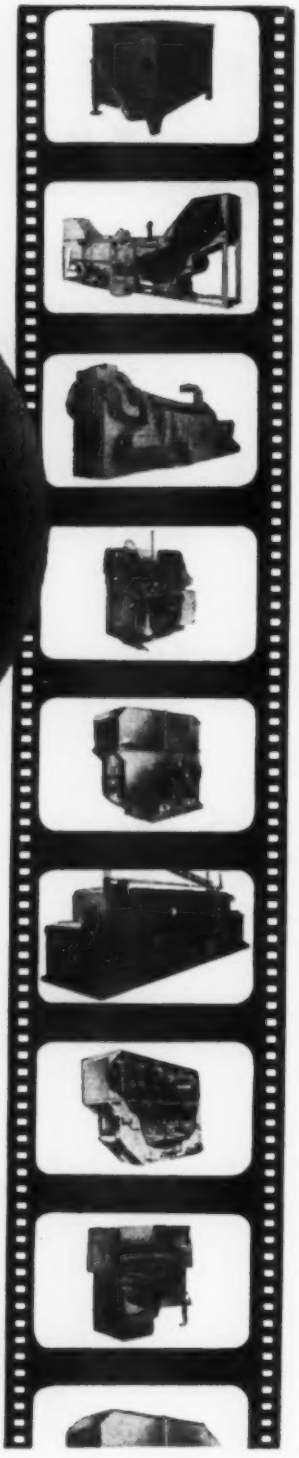

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Vibration in Machining

(Cont. from p. 702) the maximum possible amplitude is attained.

When the feed was less than the tool breadth, the self-induced vibrations were supplemented by forced vibrations. The forced vibration resulted essentially from an external periodic force which was quite independent of the system on which it acted. Under the present conditions, the forced vibration was produced by the act of cutting through metal with an undulating profile produced during the previous revolution of the tool. The wave form of the forced vibration bore a definite phase relation to the previous contour.

The above tests were made with a tool shape designed for scientific convenience rather than practical utility. Work with a more practical tool shape showed that after a few minutes' cutting time the vibration built up to about the same magnitude as that obtained in the other tests. When a small radius was lapped on the point, full vibration developed even more rapidly.

Effect of Stress Relief on Fatigue Strength*

TO DETERMINE the effect of metallurgical changes associated with welding without actually depositing a weld, tests were made on a 0.25% carbon, 0.45% manganese steel in the following conditions: Series A — as rolled; Series B — stress relieved at 1150° F.; Series C — 1-in. diameter spot at the center heated to 1100° F. and water quenched to produce thermal stresses without hardening; Series D — 1-in. diameter spot at the center heated to 1660° F. and water quenched to produce a hard structure and thermal stresses; Series E — 1-in. diameter spot at the center heated to 1660° F. and water quenched so as to produce a hard structure.

Pilot tests showed *(To p. 706)*

*Abstracted from "The Effect of Metallurgical Changes Due to Heat Treatment Upon the Fatigue Strength of Carbon Steel Plates", by Walter H. Bruckner and William H. Munse. *Welding Journal*, Oct. 1944, p. 499s to 510s.

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Stress Relief

(Cont. from p. 704) that failure at the shoulders of the fatigue specimens was prevented by local flame hardening of the shoulders. All subsequent fatigue specimens were so treated.

Static tests were made on fatigue type specimens. Except for Series B, closely checking values for tensile strength were obtained in each series. Series D had the highest tensile strength and the lowest reduction of area. Except for one specimen of Series B, Series B, C and E had lower tensile strengths than Series A. The ductility as measured by the elongation continually decreased in the order Series A to E.

Fatigue tests on three or more specimens in each series are summarized below:

Series	Cycles to Failure* Average	Minimum
A	490,200	476,500
B	276,900	168,600
C	403,430	265,900
D	798,470	584,700
E	498,550	461,800

Stress relieving reduced the fatigue strength of Series B and caused failure to occur near the shoulders. Metallographic and hardness tests showed that the region of failure was slightly spheroidized with a minimum hardness of Vickers 120. The reduced fatigue strength of this series can be ascribed in part to the probable loss of the strength of the shoulders and the consequent re-establishment of the geometric stress raisers because of the softening during stress relieving.

None of the fatigue failures of Series C, D and E occurred in the heat treated region at midlength but rather in the region between the heat treated shoulder and the heat treated portion in the center. These results would indicate that the heat treated region had a higher fatigue strength than the unaffected base metal in which failure occurred. No quantitative data were obtained on the fatigue strength of the heat treated regions. The only apparent correlation between the static *(Cont. on p. 710)*

*Stress cycle 28,000 psi. tension to 16,000 psi. compression. Column for average of results does not include an exceptionally large number of cycles obtained on two samples of Series D and one each of Series C and E, which were believed to be without significance.

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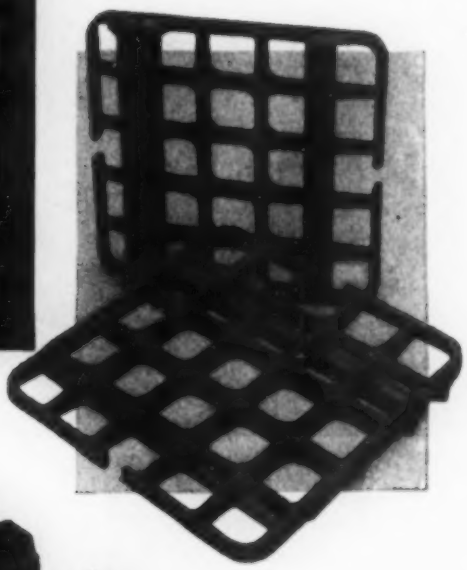

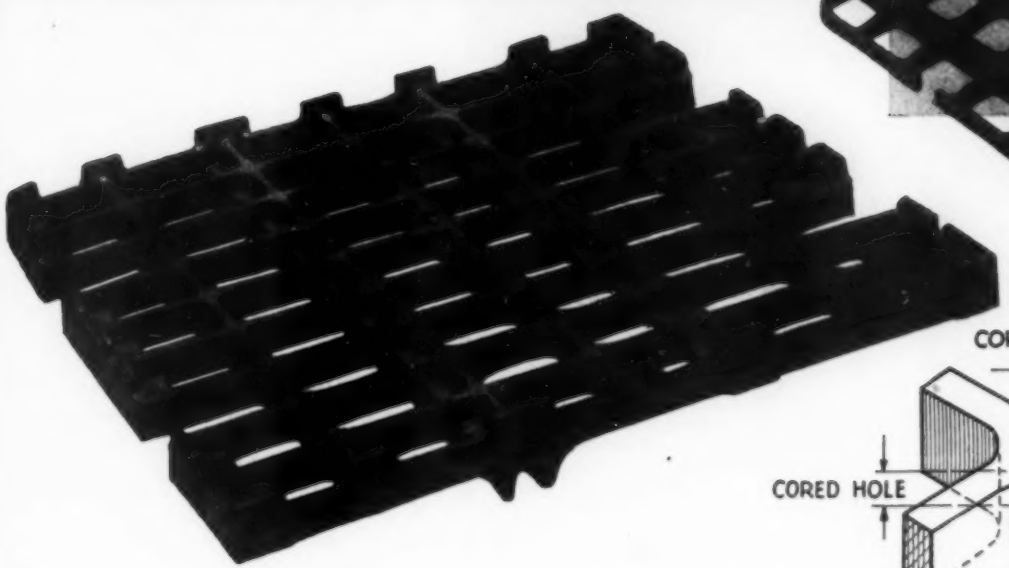

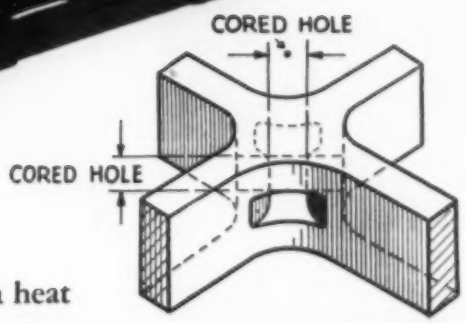

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Add the Misco principle of grid-bar design and here is the strongest, most rugged tray construction yet devised. Users are enthusiastic and almost wish they could use more. But replacements are very rarely needed because Misco trays last so long.

THE MISCO PRINCIPLE OF GRID BAR DESIGN

Grid intersections are cored horizontally and diagonally through the neutral axis. Metal thus removed from regions of low stress is added to areas of high stress, where it increases load capacity, reduces distortion, and gives much longer life. U.S. PAT. 2242554.

SPECIFY MISCO HEAT RESISTING ALLOYS

CAST • ROLLED • FABRICATED

For all Heat Treating Equipment

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ALLOY CASTING DIVISION

Michigan Steel Casting Company

MISCO
Heat and Corrosion Resistant Alloys

One of the World's Pioneer Producers of Heat and Corrosion Resisting Alloys

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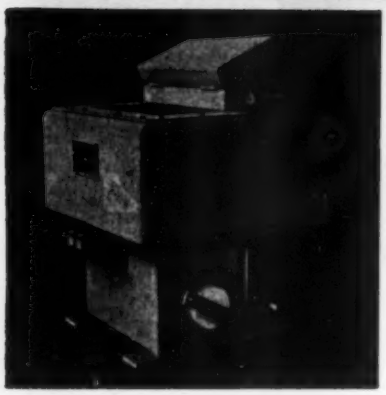


JOHNSON Seahorse
OUTBOARD MOTORS

OUTBOARD MOTORS contain a large number of aluminum die castings which provide uniformity in size, strength and quality, and avoid excess weight. High quality of castings is contributed by exclusive use of low frequency Ajax-Tama-Wyatt induction melting furnaces.

First . .

ALL ELECTRIC DIE CASTING PLANT

The photograph above shows a part of the Aluminum Alloy Die Casting Shop of the Johnson Motors Division of Outboard Marine & Manufacturing Company, located at Waukegan, Illinois, U.S.A. This is the first die casting plant in the world to use exclusively electric furnaces for melting and holding the metal to be processed in die casting machines.

A large number of Ajax-Tama-Wyatt low frequency induction melting furnaces have been installed at this plant. The small illustration gives a close-up view of the 20 kw. holding furnace. Automatic temperature control, gentle movement of the metal (which prevents segregation) and amazingly low maintenance cost are the principal features.

AJAX ENGINEERING CORPORATION, Trenton 7, New Jersey

AJAX TAMA-WYATT INDUCTION MELTING FURNACE

Associate Companies: AJAX METAL COMPANY, Non-Ferrous Ingot Metals and Alloys for Foundry Use
AJAX ELECTROTHERMIC CORP., Ajax-Northrup High Frequency Induction Furnaces
AJAX ELECTRIC CO., INC., The Ajax-Hultgren Electric Salt Bath Furnace
AJAX ELECTRIC FURNACE CORP., Ajax-Wyatt Induction Furnaces for Melting

Stress Relief

(Cont. from p. 706) tensile and the fatigue tests was the position of the failure.

An attempt was made to dissociate the effect of residual stress and metallurgical changes on the fatigue strength by testing samples of Series E which had been stress relieved at 1000° F. The number of cycles to failure approximated the number for Series B. The fatigue failure occurred in the shoulder in one specimen and in the other specimen at the same position as the Series E specimens that were not stress relieved. The only significance of these tests was to confirm the results on Series B that stress relieving reduces the fatigue strength.

Origin of Inclusions*

THREE related subjects are considered in this notable study of slag inclusions in steel. The first is new experimental work by the authors on the MnO-Al_2O_3-SiO_2 system. This is followed by a review of phase relations in the oxide systems involved in the formation of inclusions by deoxidation with aluminum and reactions of steel with pit refractories, particularly fireclay refractories. The final portion presents X-ray analyses and photomicrographs of inclusions from a number of acid and basic steels, together with recommendations for avoiding their occurrence.

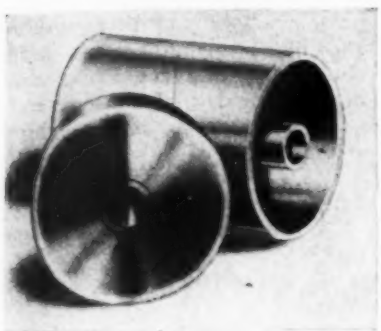
The authors' work on the MnO-Al_2O_3-SiO_2 system confirms the existence of three ternary compounds, already indicated by the work of R. B. Snow, published in the *Journal* of the American Ceramic Society for 1942, V. 26, p. 11, whose work the author reviews in detail. The ternary compounds are a feldspar, the manganese analogue of anorthite ($MnO \cdot Al_2O_3 \cdot SiO_2$); spessartite garnet ($3MnO \cdot Al_2O_3 \cdot 2SiO_2$); and the manganese analogue of cordierite ($2MnO \cdot 2Al_2O_3 \cdot 5SiO_2$). Snow's observation that the manganese analogue of cordierite has only a small field on the liquidus and crystallizes with *(Cont. on p. 712)*

*Abstract of "The Origin and Constitution of Certain Nonmetallic Inclusions in Steel", by J. R. Rait and H. W. Pinder. Advance Copy, Iron and Steel Institute, June 1946.

Lepel Spark-Gap Converters

NO. 2

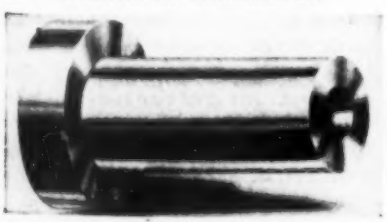
SILVER SOLDERING SIX ASSEMBLIES AT ONE TIME



Faced with a need for speeding up the silver soldering of a cup-and-tube assembly, one manufacturer called in Lepel engineers. Induction heating coils were designed to join six assemblies simultaneously. Jigs were designed to hold the prefluxed parts of the assembly and the silver rings in position for soldering.

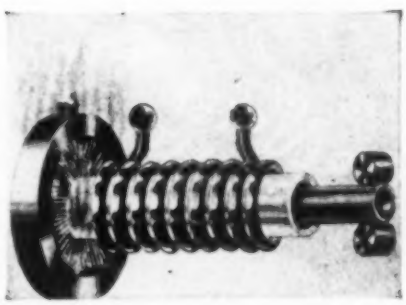
Automatic control permits the operator to assemble parts for another group of six in a duplicate heating station while the first six is being heated, at the rate of 1 every 5 seconds, to the proper soldering temperature, using a 15 KW unit. Metal discoloration, soldering time, and cost were reduced to a new low.

SPEED-UP OF A SHRINK-ON



A manufacturer of machinery speeded up a shrink-fit operation by applying his Lepel Induction Heating Unit to the job. The collar to be shrunk onto the tube was placed in a suitably designed load coil, and heated for a few seconds. Then the tube was inserted and the assembly allowed to cool. This is only one of the 25 operations performed by Lepel units in this one plant, which result in a saving of over 50,000 man-hours annually.

HARDENING STAINLESS-STEEL TUBING — TEN FEET A MINUTE, WITHOUT DISTORTION



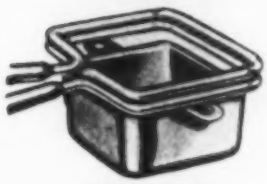
A stainless steel tubing is heated to about 2000° F and quenched in water for hardening. A tubing company is hardening such tubing at average rates of from 8 to 10 feet a minute. Heart of the automatic machine which performs this continuous heat-treating operation is a Lepel High-Frequency Induction-Heating Unit. A pair of rollers feed the tubing through a suitable heating coil and from there to the quench. One important result of this method of hardening is elimination of distortion, always a difficult problem in heat-treating.

IF YOU HAVE A PROBLEM in joining, heat treating or melting of ferrous or non-ferrous metals, chances are that some Lepel High-Frequency Induction Heating Unit can help you do a better, faster, more economical job. Lepel metallurgists and field engineers will be glad to make a thorough study of your specific problem, and help you put the right compact, Lepel unit on the job. Just call, or write, Lepel High Frequency Laboratories, Inc., 39 West 60th Street, New York 23, N. Y.

Note: Our new catalog is just off the press. Send for it.

PIONEERS IN INDUCTION HEATING

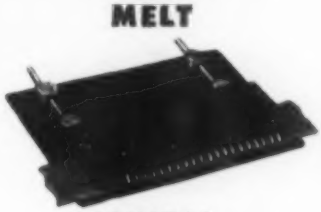
HARDEN



SOLDER

BRAZE

MELT



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Cold SPRAY-GRANODINE, is ideally suited to processing (in continuous production in power spray washers) either large or small products, rapidly, efficiently and economically. The present trend toward Granodizing attests to its efficiency and time-proved effectiveness.

AMERICAN CHEMICAL PAINT CO.
AMBLER **ACP** **PENNA.**

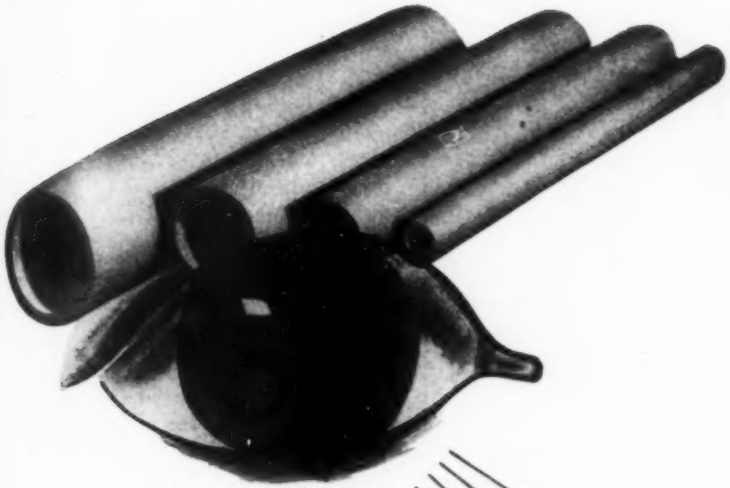
Origin of Inclusions

(From p. 710) difficulty even on initial cooling was confirmed. The melts were made by heating above the melting point, in a platinum crucible under an atmosphere of hydrogen or oxygen-free nitrogen. The melts were annealed to obtain crystallization, using temperatures between 900 and 1350° C. (1650 and 2450° F.) depending on the composition. Each specimen was polished and examined microscopically by reflected light and then powdered and an X-ray diffraction pattern obtained. The coexisting phases in the annealed specimens were:

1. Manganous oxide, tephroite, galaxite.
2. Tephroite, spessartite, galaxite.
3. Tephroite, rhodonite, spessartite.
4. Spessartite, galaxite, corundum.
5. Spessartite, manganese feldspar, corundum.
6. Manganese feldspar, corundum, mullite.
7. Manganese feldspar, mullite, cristobalite or tridymite.
8. Spessartite, manganese feldspar, cristobalite or tridymite.
9. Spessartite, rhodonite, cristobalite or tridymite.

Using published data, the authors then discuss the phases to be expected in systems which contain FeO, CaO and MgO in addition to MnO, Al_2O_3 and SiO_2. All of these oxides are considered to have a bearing on inclusions since the oxides of iron, manganese and silicon may be formed from the steel; silica is a constituent of acid and basic slags, of acid furnace refractories and of firebrick and other common pit refractories, while lime and magnesia may come from basic slags. Koerber's study (*Stahl und Eisen*, 1937, V. 57, p. 1349) of the Fe-Si-Mn-C-O system is reviewed, to show that steels of certain manganese and silicon contents will react with silica. The silica is reduced to silicon, which dissolves in the steel, while manganese in the steel is oxidized to form MnO which dissolves in the surface layer of the refractory.

The authors then review some of the senior author's earlier work published in 1943 in *Transactions* of the British Ceramic Society, on runner brick slags and inclusions in castings (made of acid steel without any aluminum addition) teemed through magnesia nozzles and bottom-cast *(Cont. on p. 714)*



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FURNACE operations which today often demand a refractory tube able to withstand high temperatures and to give long, economical service, are looked upon by Norton Company as the logical application of the new "Pure Oxide Refractories". ALUNDUM* furnace tubes, which are essentially sintered alumina without any bond, do provide greater refractoriness and much longer life and thereby greatly extend the utility of the furnace tube line of Norton Refractories.

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The New

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THE NEW G-55 HAND GUN was designed especially for small-quantity users of the larger sizes (7/32", ¼", 9/32") of Cherry Blind Rivets. (Used with an adapter, it also installs the smaller rivets.) The more expensive pneumatic guns are primarily production line tools. But for small-quantity rivet installation, or for field work where air pressure is not available, the hand gun is perfect. The relatively inexpensive G-55 Hand Gun is light weight and easy to handle.

CHERRY BLIND RIVETS are available in aluminum, steel, brass and Monel.

For more information regarding Cherry G-55 Hand Gun, and other Cherry Rivet products, write to Dept. J-194, Cherry Rivet Company, 231 Winston Street, Los Angeles 13, Calif.

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LOS ANGELES 13, CALIFORNIA

Origin of Inclusions

(Cont. from p. 712) through fireclay runner brick. Two types of fireclay brick were used, a more siliceous brick which contained about 13% of quartz and a more aluminous variety which contained less than 1% of quartz.

Slag taken from between the runner brick and the steel in the runner, inclusions extracted from the steel in the runner, and inclusions found on the surfaces of the cast ingots consisted almost entirely of MnO, SiO_2 and Al_2O_3 and had SiO_2:Al_2O_3 ratios lower than those of the firebrick runners before use. This confirmed the postulate that manganese in the steel had preferentially reduced silica in the firebrick and that the MnO so formed had fluxed the refractory, forming a MnO-SiO_2-Al_2O_3 slag. Since the more siliceous firebrick runners were much more rapidly attacked than the more aluminous brick, the author concludes that silica in the form of quartz is the constituent most rapidly attacked by manganese in the steel. Recalculated on the basis of $MnO+SiO_2+Al_2O_3=100\%$, the slags from the casting runners fall in the mullite field. A few of these slags were subjected to X-ray analysis and were found to consist of mullite and glass; mullite, quartz and glass; or glass alone.

Runner and tun-dish slags, and inclusions from the bottom-cast steels described above, and from basic and other acid steels, were subjected to X-ray analysis. The constituents identified in this way were correlated, at least in part, with the appearance in polished section. The minerals identified by X-ray analysis were: manganese anorthite, mullite, cristobalite, tridymite, spessartite, spinel (chiefly $MgO\cdot Al_2O_3$), spinel (a complex wherein RO=FeO, MgO, MnO; $R_2O_3=Fe_2O_3$, Al_2O_3), α alumina, γ alumina, rhodonite, gehlenite, pyroxene (isomorpnous with enstatite), and monoclinic pyroxene (diopside type).

Most of the observed inclusion minerals are the products of reaction of the steel with deoxidizers or refractories. In addition to these the $MgO\cdot Al_2O_3$ occurred in steel to which 8 oz. of aluminum per ton had been weighted with ferromanganese and added in the furnace to a basic electric heat. The spinel is attributed to reaction of the aluminum with the dolomite furnace bottom. The occurrence of gehlenite and pyroxenes con- *(To p. 716)*

Hagan *Automatic* HEAT TREATING FURNACES

TYPICAL LAYOUT OF Hagan Engineered Automatic Heat Treating Unit for large automotive manufacturer.

FEATURES include continuous automatic hardening, quenching and drawing singly or in quantity . . . mechanical reloading after quenching, on carriers . . . ADJUSTABLE TIMING . . . AUTOMATIC UNLOADING . . . all characteristic of Hagan engineering ability to design and build furnaces to fit your specific needs.

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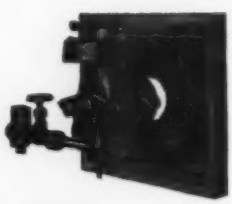

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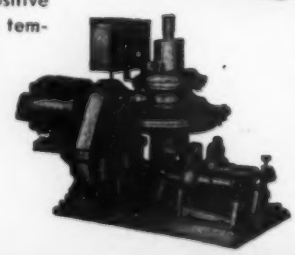

WRITE FOR BULLETIN M-550

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ENGINEERS & MANUFACTURERS OF INDUSTRIAL HEATING EQUIPMENT

Origin of Inclusions

(From p. 714) taining CaO indicates that lime-bearing slag combines with the surface of the ladle brick, which on subsequent use becomes a source of inclusions.

Recommendations for avoiding inclusions are:

1. Deoxidation with silicon before adding aluminum.
2. Confining aluminum additions to the ladle — since, if added to the furnace, aluminum was found to react with the dolomite hearth to form spinel inclusions.
3. Use of bottom casting.
4. Use of firebrick refractories which are free from quartz.
5. Boiling fireclay nozzles in tar.
6. Thorough cleaning of slag from the ladle after each heat.
7. Development of basic patching cements for launders, ladles, tun-dishes, and other equipment to supplant the siliceous materials now in use.

Anodic and Organic Finishes

THE FORMATION of self-coloring anodized coatings on aluminum by the oxalic acid bath process is described at length by H. Fischer and N. Budiloff.* It has been known for some time that in the anodic oxidation of aluminum and some aluminum alloys, oxide films with a characteristic self-color are produced under certain conditions. Electrolytes based on oxalic acid produce color tones varying from a weak yellow to a dark brass or old-gold tone. These effects should find considerable use in architecture. These colored coatings differ from those produced by special decomposition or structure of the base metal, but heretofore little information has been available regarding their nature. It is now suspected that they originate from some decomposition product of the oxalic acid.

High temperature in the oxide layer during the process of formation is necessary to produce a colored film, but in addition there are certain chemical influences of the electrolyte. If it *(Cont. on p. 718)*

**Korrosion und Metallschutz*, V. 20, No. 3, March 1944, p. 115 to 119.

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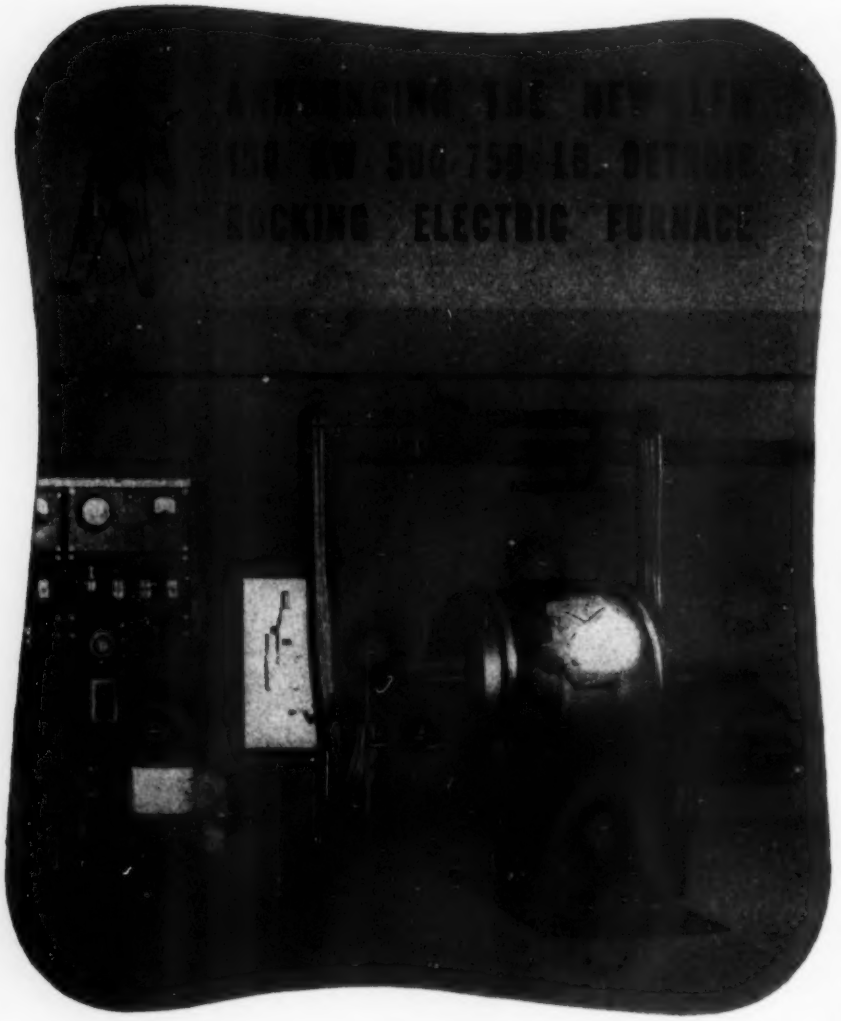
WISCONSIN STEEL



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DETROIT ELECTRIC FURNACE DIVISION
KUHLMAN ELECTRIC COMPANY • BAY CITY, MICHIGAN

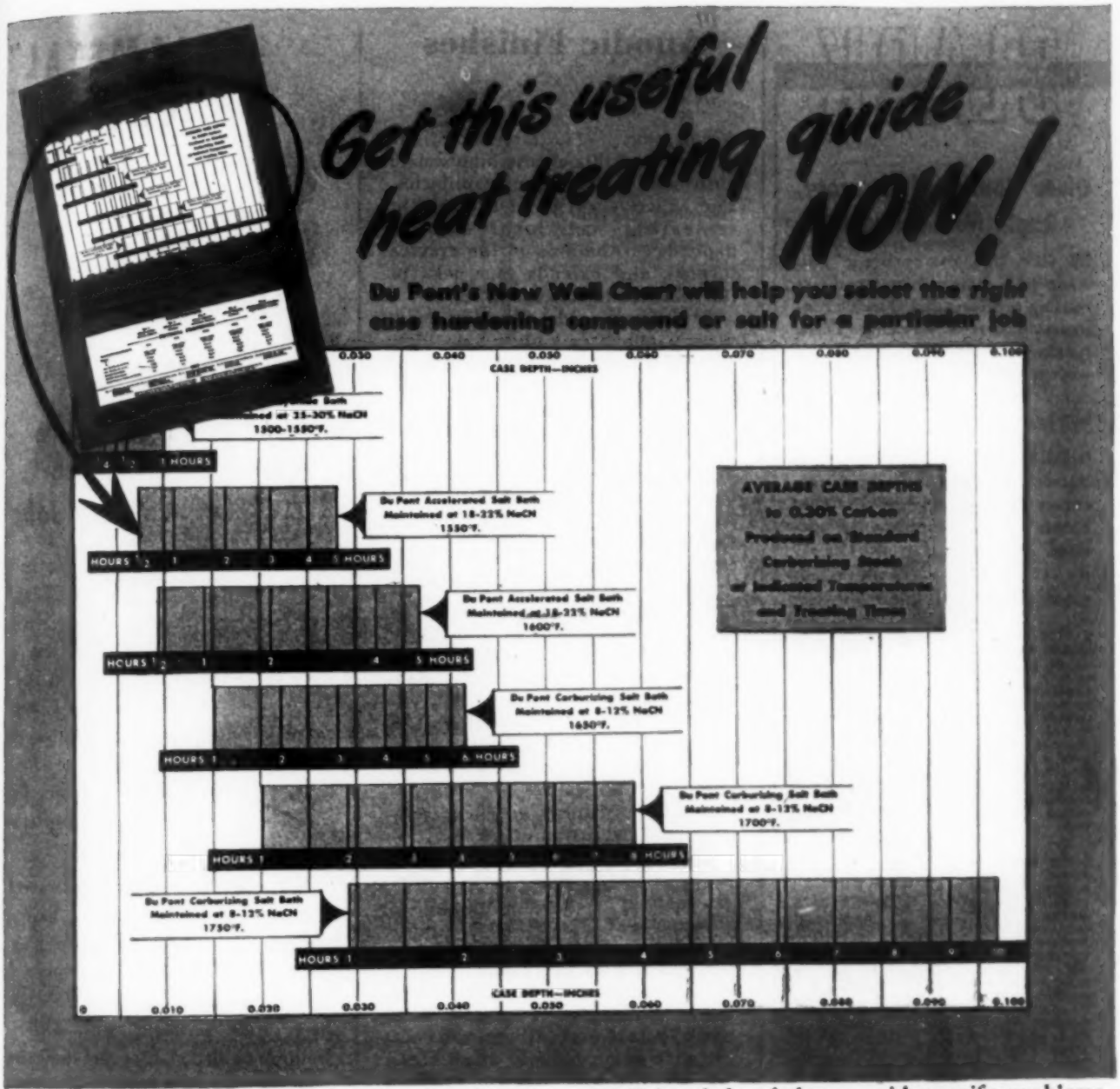
Anodic Finishes

(Cont. from p. 716) be assumed that the coloring constituent of the oxide layer is formed by the thermal decomposition of organic substances in the fine capillaries of the oxide film, then the formation of a colored coating by the decomposition of pure oxalic acid would not be anticipated. Investigation of various electrolytes indicated that oxalic acid containing glyoxylic acid was much more effective than pure oxalic acid in producing stable colored films ranging from yellow to dark brown. The decomposition product of the glyoxylic acid, produced by heat during the film formation, served to produce the characteristic and stable self-coloration of the film. It was reasoned that in the anodic formation of the oxide layer, chemically pure aluminum simultaneously passes into solution. In this way, the oxalic acid is partially reduced to glyoxylic acid and other compounds. The anodic process and chemical solution produce heat, which builds up in the fine capillaries of the oxide layer (a poor conductor of heat). The yellow to brown decomposition product which serves to color the film is then formed.

Bichromate in Anodized Films — In another paper by Fischer and Budiloff★ the sealing effect of bichromate on damaged anodized films on aluminum alloys has been studied. It is known that the anodically produced oxide film on aluminum and its alloys consists of a system of the finest capillaries, and such a film offers no satisfactory corrosion protection without some subsequent treatment. One of the most effective post treatments consists in impregnating the oxide layer with hot bichromate solution. The presence of excess bichromate in the oxidized film, as indicated by a bright yellow color, is of considerable practical importance, and provides the explanation for the superiority of the bichromate sealing treatment over other finishing methods for anodized films.

An explanation proposed for this is that if the anodized film is damaged by scratches or crevices, the excess bichromate present locally re-seals the damaged portion of the exposed base metal by its oxidizing effect. The useful protective effect of the anodized film may therefore persist for a rela- *(Cont. on p. 720)*

★*Korrosion und Metallschutz*, V. 20, No. 3, March 1944, p. 129 to 131.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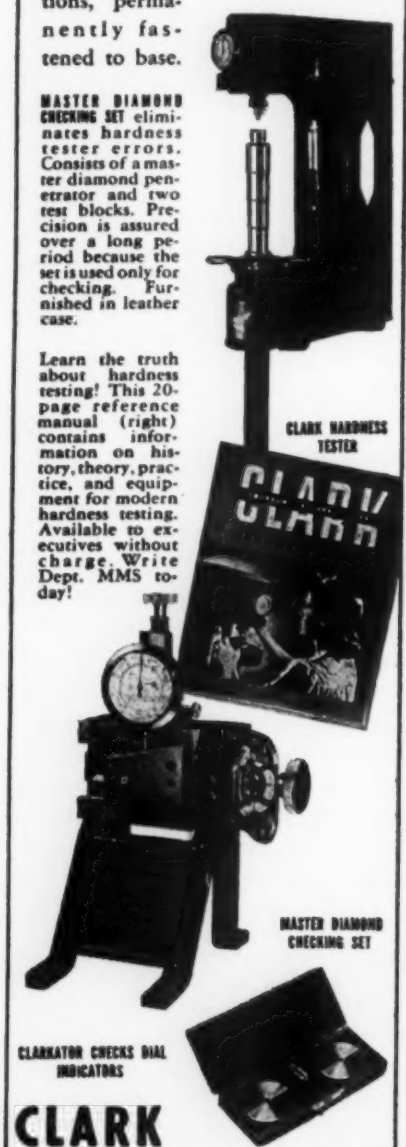

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Anodic Finishes

(Cont. from p. 718) tively long time, by virtue of this excess bichromate absorbed in the film capillaries. The effectiveness of bichromate in re-sealing such local damage depends on the area of the crevice formed, and extends to cracks in the film 0.04 to 0.08 in. wide.

Anodized oxide films on magnesium alloys and phosphate films on iron or zinc show no such healing effect on impregnating with bichromate solution at points of localized damage. The treatment is also ineffective on chromate films on zinc produced either by dipping or by anodic treatment.

Organic Films Capable of Deformation — Considerable interest is being shown by the German metal fabrication and forming industry in methods by which an organic finish (such as a varnish) may be applied to metal sheet or blanks before forming into final shape by drawing on a mechanical press. Patent literature of several countries has recently carried many references to such a finishing treatment, and the special properties of a suitable organic finish have been discussed by H. F. Sarx.★

Varnishes are used for this purpose, and are usually baked after application. Good adhesion to the base metal is a requisite, but other properties of the lacquer coating will vary with the precise nature of the subsequent forming operation. Although it would seem unlikely that a relatively soft coating such as an organic finish could withstand such severe working requirements as, for example, in the manufacture of metal boxes and containers, the process lends itself admirably to this purpose. Thread rolling may also be practiced with these pre-applied finishes. Two stages during fabrication require special attention to avoid damage to the coating — namely, a deep draw and the formation of sharp edges (two dangers often encountered simultaneously). High extension and contraction stresses are imposed on the coating during such forming processes.

Mr. Sarx believes that it is incorrect to specify elasticity as a desirable film property in this connection, since such a film would tend to spring back after the forming process. The film coating should tend more toward *(Cont. on p. 722)*

★*Korrosion und Metallschutz*, V. 20, No. 1, January 1944, p. 60 to 63.

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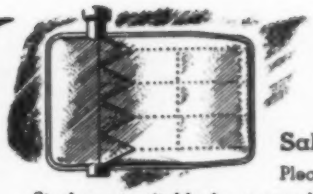

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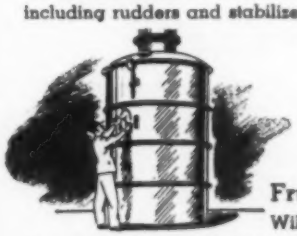
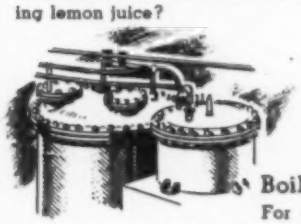


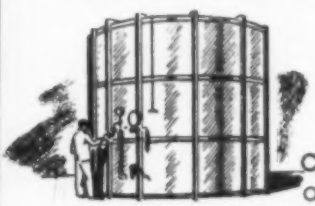
Fruit Juices?

Will E-S 18-8 Stainless (Type 302) canning reservoirs be all right for handling citrous fruit juices including lemon juice?



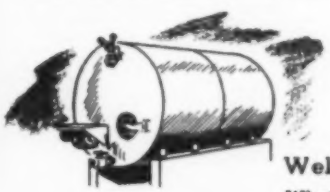
Boiling Peroxide?

For a new oxidation process using boiling concentrated hydrogen peroxide, would low-carbon E-S 18-8 stainless (Type 304) containers be resistant?



Chloride Storage?

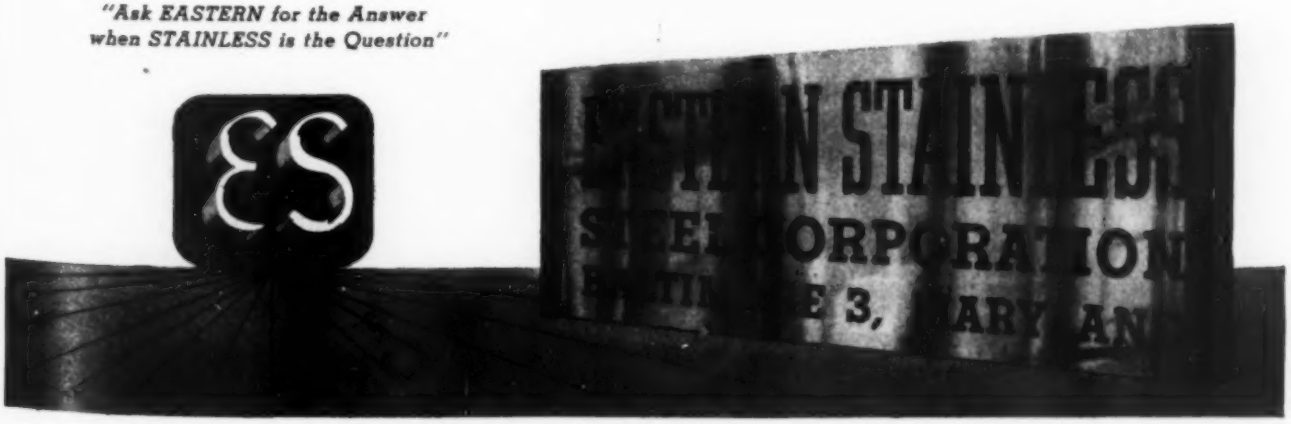
Our processing involves storing cold alkali-metal chloride solutions (aqueous) in E-S 18-8 stainless tanks. How can we inhibit pitting at the liquid line?



Welded Vessels?

What type of Stainless would you recommend for large all-welded autoclaves to handle reactions of maleic anhydride in making synthetic resins?

ES



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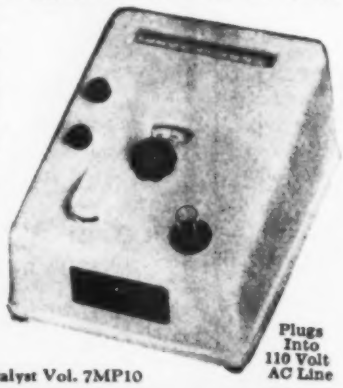

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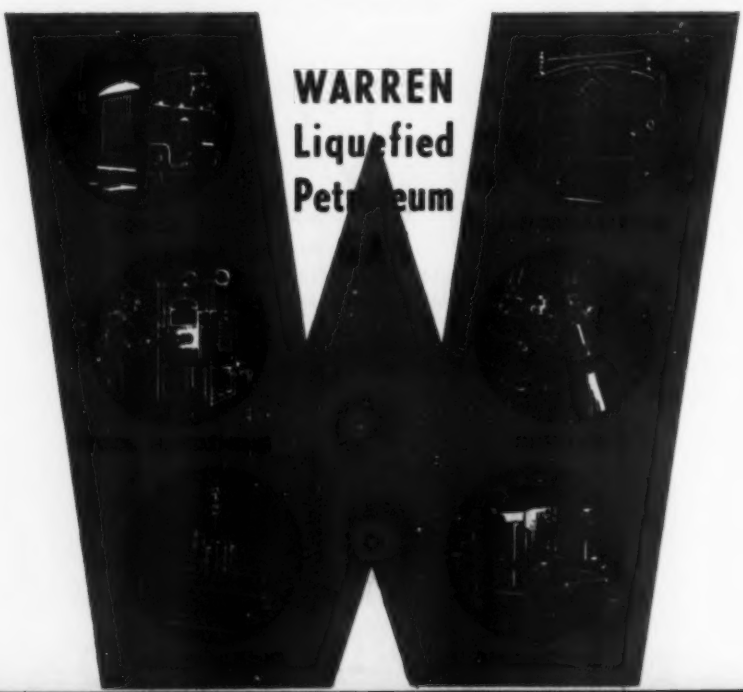

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Anodic Finishes

(From p. 720) plasticity so that it can flow with the metal under the drawing pressure. This requirement is particularly important in forming articles with sharp edges. Film thickness is also a factor; pre-applied thick films do not form as readily as thinner ones.

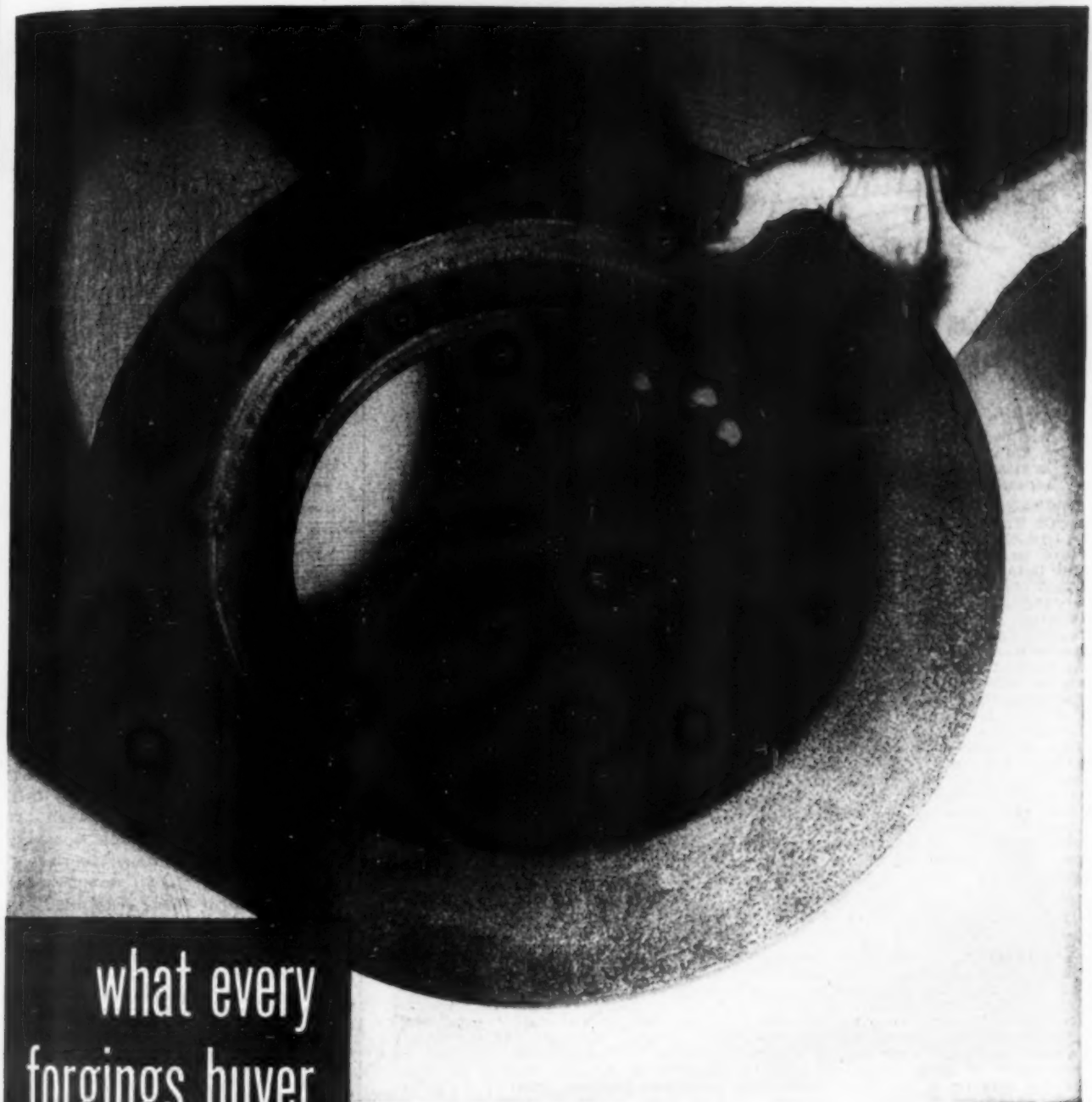
Since this type of finish is largely used for food containers, the chemical resistance of the enamel is of considerable importance. Up to eight years ago, these finishes were compounded almost exclusively on an oil basis, but more recently synthetic resin finishes are coming into favor. The phthalate resins and (what is almost the same thing) the alkyd resins are most suitable. The compounding agents for these synthetic resin finishes are the fatty acids, phthalic acid and glycerine. These finishes have the advantage of an appreciably short drying and baking time. These special characteristics of an alkyd resin film can be favorably combined, by suitable compounding, to provide an excellent film. For really satisfactory large-scale operation careful cooperation is necessary between paint manufacturer and metal fabricator.

Cutting Fluids

AT THE Institution of Mechanical Engineers' conference on Machinability held in London in May, an account was given of the studies on cutting fluids conducted by the Department of Munitions in Australia (*Engineering*, June 14, 1946, page 570). The conclusions could be summarized as follows:

First, experiments with a number of oils containing essentially the same sulphur-chlorine base, but blended with mineral oil to different viscosities, indicated the significance of viscosity and provided some evidence as to the effect of base concentration for a wide range of operations. The work had suggested that one base was satisfactory for a wide range of operations, but that the base concentration should perhaps be somewhat higher in threading and broaching than in other operations. That conclusion was consistent with statements in the literature.

Second, the performance of cutting fluids in *(Cont. on p. 724)*



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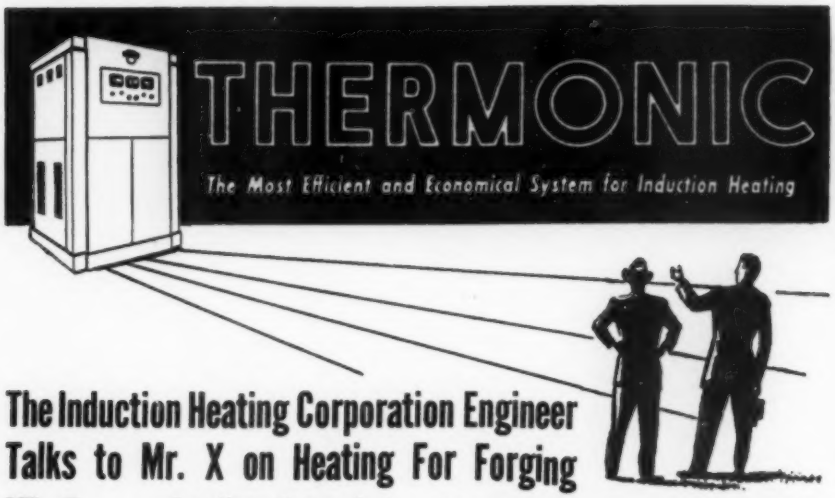

The Induction Heating Corporation Engineer Talks to Mr. X on Heating For Forging

MR. X . . . . I gather, from what you've told me about induction brazing, that heat penetrates through the entire joint area. I thought induction heating was suitable for surface heating only.

ENGINEER . . . . I'm afraid I've given you the wrong impression. While it's true that electrical energy is converted to heat energy at the outermost surface of the metal being heated inductively, this heat tends to be conducted into the inner layers, resulting in a definite temperature gradient across the material. The steepness of this gradient depends on the conductivity of the metal and the relative rates of energy input to the heat-generating layer. In the case of surface hardening, the input rate is maintained as high as possible in order to confine heat to the outer surface and remove it by quenching before it can be conducted to the interior. For forging work, however, where deep heating is required, the input rate per unit of surface area is lowered so that the temperature gradient from outside to inside is flat or negligible.

MR. X . . . . Just how does your THER-MONIC Induction Heating equipment fit into the forging shop?

ENGINEER . . . . Induction heating equipment is installed on the production line next to the forging machines. Parts are rapidly brought up to forging temperature and are fed in a continuous, steady flow to the forging machines. One of the main advantages of using induction heating for forging is its short heating cycle, compared to furnace methods, and the resultant minimum of scale.

MR. X . . . . How can induction heating minimize scale?

ENGINEER . . . . Because induction heating equipment heats parts with great rapidity, they are at the high temperature where scale takes place for a relatively short time, compared to overall heating methods. Thus, very little or practically no scale formation results. By minimizing scale, induction heating boosts forging die life as much as 300 percent and prevents die sticking. Elimination of the scale problem has saved as much as 5 percent of the total weight of forgings, normally lost in the form of scale. No de-scaling is necessary. Since a minimum of scale is pounded into the forging, secondary machining and finishing costs are reduced. Absence of scale means a better finished product and fewer rejects. Induction heating, however, effects other striking economies, aside from those resulting from scale elimination.

MR. X . . . . Speaking of savings, isn't the initial cost of induction heating equipment much higher than that of gas or oil-fired furnaces? Will these savings compensate for the higher equipment cost?

ENGINEER . . . . Yes, Mr. X., Induction Heating equipment costs almost four times as much as a standard forging furnace. The money-saving advantages of induction heating more than counterbalance the equipment cost, however. Savings from scale reduction alone more than justify the greater investment. Induction heating operation costs are lower than for furnace heating since power is used only when parts are heated. No energy is wasted in warming-up periods, and furnace maintenance costs are done away with. Expensive ventilating systems and mid-summer slowdowns are eliminated through the improved working conditions of induction heating. The induction heating unit acts as a forging output regulator. If forging machines should require unexpected maintenance, which necessitates their sudden shutdown, further heating of parts may be stopped without loss by simply pushing a button. In contrast to batch-type furnace heating methods, induction heating prevents the possibility of having a large number of heated parts accumulate and cool, or remain at high temperature too long in the furnace and take on additional scale while the forging machines are undergoing repair. Unskilled help can easily operate this equipment. Forging quality is improved through greater uniformity in heating results. Costs are repaid with profits by the savings effected by using induction heating for forging work.

MR. X . . . . You have a pretty strong argument in favor of induction heating for forgings.

ENGINEER . . . . Yes, THER-MONIC Induction Heating equipment has proven a very valuable tool to the forging and metal-working industry.

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Cutting Fluids

(From p. 722) machining operations had been compared with friction measurements, using the Bowden-Leben machine. The results suggested that there was no general correlation. This might be due, in part at least, to the considerable difference in sliding speeds in the machining and friction tests, but even at higher speed sliding plane surfaces could not be expected to develop temperatures comparable to those existing at a tool tip.

Experience had shown that some soluble oils or pastes have very good lubricating effects. One of the soluble pastes developed by Vacuum Oil Co. in Australia had given very good results in broaching a nickel-chromium steel and in reaming the Bofors barrel — incidentally, operations at low sliding speed. It is also doubtful if sulphurized oils should be classed primarily as coolants, even though friction and presumably temperature was reduced on jobs where they replaced mineral and fatty oil blends, for specific heats of non-soluble oils are generally similar.

One approach in the search for a cutting oil that would help reduce the friction between the nose of the tool and the work was to study its "boundary" lubricating properties at high temperatures and loads, for these reasons:

It is known that when unlubricated surfaces are rubbed together, the metals flow plastically at the regions of contact until the area of contact is sufficient to support the applied load. Metallic junctions form over that area, and it is the shearing of those junctions that constitutes the frictional force. If a lubricant is placed on the surface, and the pressures are too high for fluid lubrications to occur, the lubricant is squeezed out, and a film of lubricant is left one or two molecules thick, whose main purpose is to reduce the amount of intimate metallic contact between the surfaces, thus reducing friction and wear. If the surfaces are hard, the pressure that the film has to undergo is considerably increased; nevertheless, most "good" boundary lubricants are quite effective on hard surfaces. Because the pressures are high, however, the local temperatures developed during sliding would be much higher with hard metals than they would be under comparable conditions with soft metals; and *(Cont. on p. 728)*

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Cutting Fluids

(Cont. from p. 724) therefore one of the crucial tests of any lubricant when the pressures are high is not so much that it should function under high pressures but that it should function at the high temperatures that were reached during the sliding process. The search, therefore, for a good extreme-pressure lubricant, that could be used to reduce the friction between the nose of the tool and the work, resolved itself largely into a search for a boundary lubricant which operates effectively at high temperatures. Of course, if that lubricant also acts as a coolant, so much the better.

Recent Australian experiments showed a good correlation between lubrication properties of a series of cutting oils at room and at elevated temperatures as determined in laboratory tests and in turning tests in the shop. In one case this correlation failed, but it was believed that it was due to the formation of a built-up edge which prevented action at the surface of the tool. This brings up the point that the tool and work must be accessible to the lubricant.

In another series of tests, a drawing operation involved metallic deformation at high pressures between wall and die, and developed high temperatures. The laboratory performance agreed very well with the drawing operation in the shop; it was that work which led to the development of a soluble oil now widely used in Australia.

The method of application of the emulsion is of wide interest. If an ordinary soap solution is placed on a surface and a friction test done on it, the lubricant will break down at 100° C. from evaporation of the water, but if that lubricant film is deposited from a very volatile solvent it will lubricate up to much higher temperatures. That fact had a practical application in drawing operations where, if the emulsion is applied as a dry film by immersing the metal in a hot solution and taking it out so that most of the water evaporates, a much better performance is obtained. Those experiments showed that, if the friction between the work and the die could be reduced under the actual conditions of operation, the practical results reached were much more satisfactory for all sorts of machining operations.

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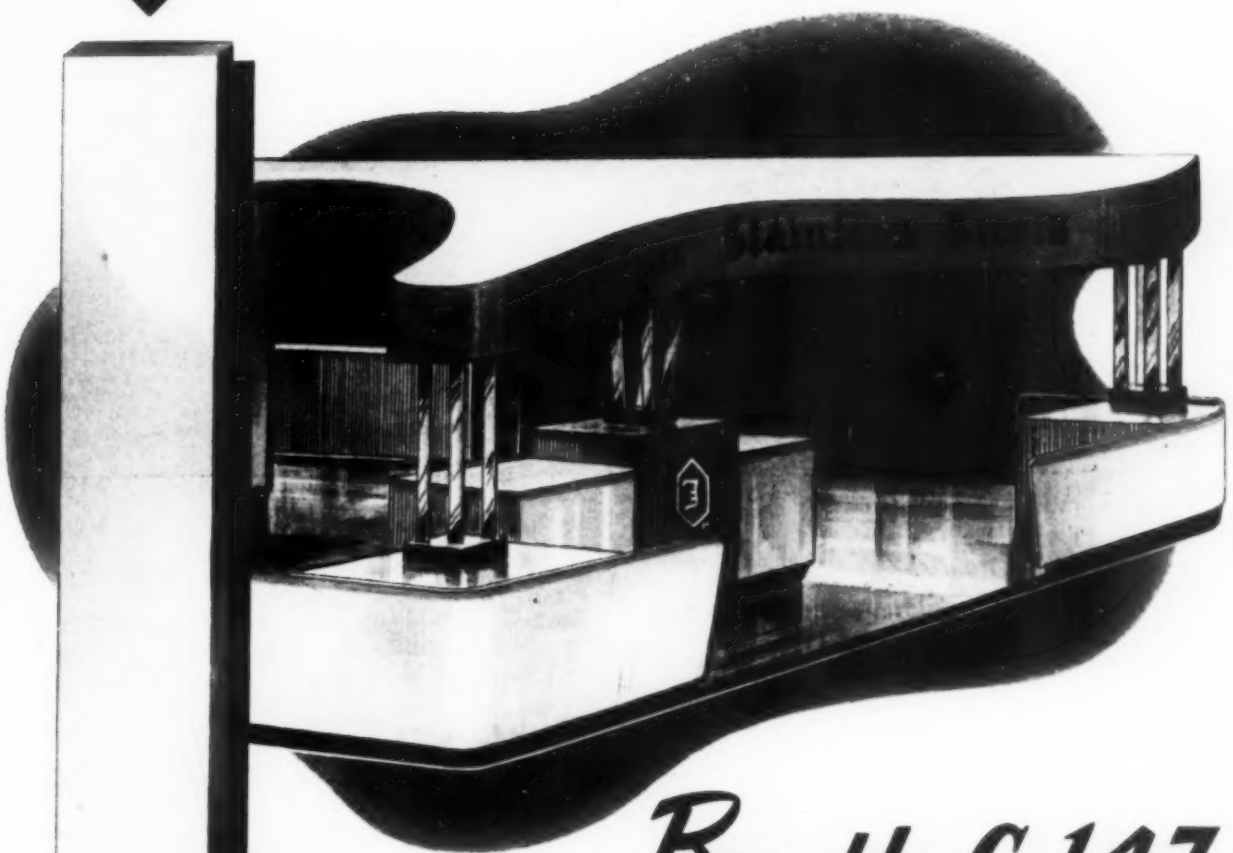

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